5.0 CONTAMINANT TRANSPORT MODEL

5.1 Preface

The material presented in this Section is intended to provide an overview of the validation and use of the Contaminant Transport Model (CTM) during the FS. A more technically detailed development is provided in Appendix C.

5.2 Objective and Approach

The objective for developing the CTM is two fold:

1. To help characterize the nature and extent of groundwater contamination at the Site.
2. To aid in the *Feasibility Study* (FS) process by providing a cause-and-effect relationship between the sources for groundwater contamination and groundwater quality downstream of those sources. This allows for the evaluation and comparison of remedial alternatives and for the determination of the extent of remediation required.

To these ends, the CTM is *developed*, *verified*, and *implemented* as follows:

1. <u>As a surrogate for reality</u>. The CTM is a "model" of reality that is closely tied to measured field data (i.e., water level measurements and contaminant concentration measurements). The CTM includes the important physical processes that govern how and where contamination is getting into the aquifer (i.e., sources of contamination) and, once in the aquifer, the ultimate fate of that contamination (i.e., extracted by a pumping well). The CTM is *calibrated* and verified as being an acceptable model of reality by *comparing model predictions to site-specific data associated with past and current conditions at the Site*.

2. <u>As a tool to predict future conditions at the Site</u>. Once accepted as a surrogate for reality based on *recreating past and current conditions*, the CTM is used to *predict future conditions* at the Site. Because the location and intensity of contamination in the aquifer is directly related to the sources of contamination, the CTM is used to define the relationship between contamination entering the aquifer at source areas and future groundwater quality throughout the impacted aquifer. It is in this role that the CTM is used during the FS, to assess how remediation of sources of contamination affects overall groundwater quality.

As indicated above, the *first step* is to verify that the CTM provides an acceptable interpretation of what is actually going on at the Site. In order to gain an understanding of the factors that combined to result in the current site conditions the CTM integrates the following information:

1. An historical perspective of site-specific and regional land use practices.
2. A site characterization database which defines the site hydrology, geology and water and soil quality.

As discussed earlier, historical information on the source areas is summarized in Section 2.0 and site characterization is provided in Section 3.0.

From this understanding, a *conceptual model* of the physical system is developed. Specifically, based on an assessment of site characterization data, the current conceptual model indicates that the objectives for the analysis can be achieved if the following physical features can be defined:

- The physical properties of the aquifer (i.e., the distribution of sand, silt and clay layers [see Section 3.2.1]),
- The major stresses on groundwater flow (i.e., the Toms River, rainfall, and water supply wells [see Section 3.2.2]), and
- The mechanisms that allow contamination to leach from waste impoundments (i.e., source areas to the aquifer (i.e., rainwater becomes contaminated as it leaches through a source area).

In addition to these features, the database shows that the character of the contamination at the Site can be effectively represented by modeling the behavior of a selected list of the chemicals, the so-called *Contaminants of Concern* (COCs). A detailed discussion on the definition of COCs is provided in Section 3.1. In the context of developing the CTM, the COCs are deemed representative because:

- They constitute most of the contaminant mass.
- They are the most widely distributed compounds.
- They represent the most toxic compounds.
- They represent a broad spectrum of chemical properties (i.e., solubility in water and susceptibility to biological degradation).

The conceptual model is incorporated into the CTM by employing a *mathematical representation* of the important physical processes. The mathematical representation consists of a system of conservation equations (for example conservation of mass and volume) defined by a set of quantifiable *parameters* (i.e., the intensity of rainfall and the properties of the soils).

If the description of the physical problem is complete, then model *validation* is achieved in large part through *model calibration*. Model calibration is the process where the model's *parameters* that most strongly affect model results are adjusted so that the model predictions correspond to field measurements. In this way, the CTM is linked to the site-wide database, which consists of groundwater and soil quality data and surface and groundwater flow data obtained at multiple locations in space and time.

If the CTM parameters cannot be adjusted so that the model provides an acceptable representation of the data, then the entire modeling effort has to be reassessed. This may include the gathering of additional data (i.e., measure groundwater attributes in a critical zone of the aquifer) and the updating of the conceptual model (i.e., identifying and including geologic features affecting groundwater flow). Figure 5.1 illustrates the *iterative* nature of this first step of model development.

Once an acceptable match to data has been achieved, the second step of model use can be realized. That is, by assuming that the understanding of past behavior (step 1, Figure 5.1) is the key to understanding future behavior (step 2, Figure 5.1), the CTM can be used to predict the cause-and-effect relationship between a remediation scenario (i.e., the remediation of a source area) and aquifer restoration.

During FS activities, the calibrated CTM is used to quantify the relationship between source area remediation and the following remediation parameters:

- *Time of Compliance* **-** under different remediation scenarios, assess the time it takes for the aquifer to be restored.
- *Preliminary Remediation Goals* – quantify the necessary level of source area remediation so the groundwater quality standards are met at a particular time of compliance.

The remainder of this Section is dedicated to detailing the CTM's role during this FS. This includes the description of the conceptual model developed for the Site and the procedures used for CTM calibration. After this discussion, the results obtained from the calibration effort are presented. Following this presentation, in Section 6, the methodology and results of the analysis of *source area remediation to meet compliance requirements* are presented.

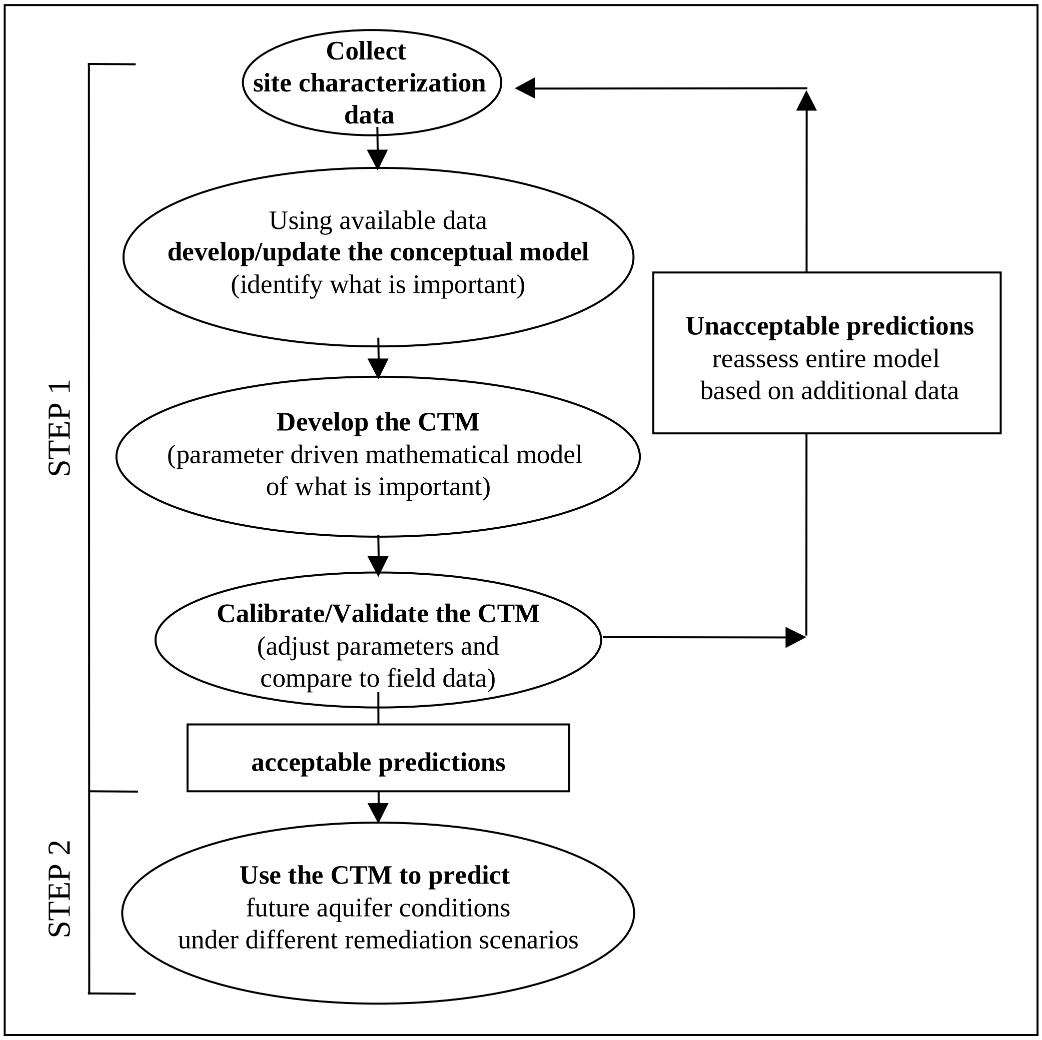

Figure 5.1 – Flow chart showing that the iterative development of the CTM as a predictive tool to assess the relationship between aquifer restoration and remediation activities.

5.3 Conceptual Model and Calibration

As stated above, the CTM is a "model" of what is going on in the subsurface at the Site. It describes how contamination gets into the aquifer (source mass loading) and, once in the aquifer, the model predicts the movement of that contamination. In this Section we provide an overview of CTM development from conceptual model to calibration. This includes a discussion of the important model calibration parameters and examples of the calibration results. A detailed presentation of CTM calibration is provided in Appendix C.

In simple terms, moving water is the vehicle for contaminant transport. As water leaches (percolates) through a source area (i.e., rainfall infiltrates through a former disposal basin), it picks up contamination (a dissolution process). This, now contaminated, water makes its way into the aquifer where it continues to flow away from the source.

From this concept, in order to understand the aquifer contamination problem at the Site, we must first understand how groundwater moves at the Site. Therefore, as a way to simplify the overall development of the CTM for the Site, we separate the model into two sub-models.

- Sub-Model 1: The Groundwater Flow Model – defines how groundwater moves throughout the Site. This includes all major influences on groundwater flow: geologic (i.e., the aquifer consists of layered sand, silt, and clay), and hydrologic (i.e., infiltration from rainfall, the Toms River, and water extraction wells).

- Sub-Model 2: The Contaminant Source and Transport Model: defines the distribution of contaminants at the Site. The source conditions are characterized in terms of location, size, chemical composition, and the time-varying potential for leaching contaminant mass into the aquifer. That is, given an estimate of how much water flows through a source area (from flow model) and the total source mass and composition, estimate how much chemical leaches out of the source over time. The transport conditions define the geometry of the plumes that emanate from the sources, where plume geometry is mostly controlled by the location of the source and the direction of groundwater flow (from flow model). Transport parameters that affect concentration magnitude in the plume include source strength, dispersive mixing, chemical adsorption to the soil, and biological decay.

As illustrated in Figure 5.2, the solution of the overall contaminant fate and transport problem can be obtained from the sequential solution of the flow problem and the source and transport problem. Note that the arrows in Figure 5.2 represent the direction of data transfer.

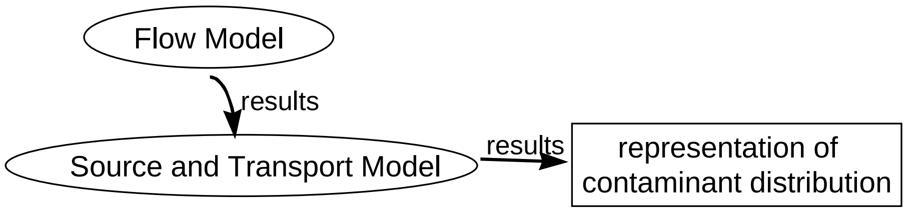

Figure 5.2 - A flow chart illustrating, in concept, how the two major parts of the CTM combine to describe the contamination problem at the Site, where the arrows indicate the direction of data transfer.

The remainder of this subsection describes the database, conceptual model, and CTM calibration results for each of the two sub-models introduced above.

5.3.1 THE GROUNDWATER FLOW MODEL

As discussed above, in the context of modeling the groundwater contamination problem at the Site, the purpose for developing the groundwater flow model is to define water movement at the Site. This information is used by the CTM as follows:

- In the definition of contaminant source terms by providing an estimate of how much water moves through a source area over time, and
- In the definition of contaminant transport away from the source by providing an estimate of the speed and direction of water flow.

The data requirements (and data source) for the groundwater flow model are as follows:

- Geology (borings, monitor wells, United States Geological Survey)
- Precipitation (United States Geological Survey)
- Ground water levels (monitor wells)
- River levels (United States Geological Survey gage stations)
- Pumping well rates (operational records)

Section 3.2 details the geologic and hydrologic site characterization afforded by this data. Figure 5.3 provides a conceptual view of the CTM in cross-section. The CTM models the flow and transport properties of the Upper Sand Aquifer. The different geological horizons are represented as model “layers” (seven in all and not necessarily horizontal surfaces). Because the Primary Cohansey is relatively thick, and because it plays an important role in defining the contaminant transport problem, it is separated into three model layers.

In addition to showing the representation of the Upper Sand Aquifer, Figure 5.3 illustrates the concept that the site-wide flow problem can be separated into three flow zones:

1. The vadose zone (also called the unsaturated zone), the zone where both air and water coexist in the soil.
2. The perched water zone, an intermediate zone of water-saturated soil caused by intermittent layers of poorly draining soil above the aquifer (in this case clay).
3. The saturated zone, or in this case the Upper Sand Aquifer, the zone of regional groundwater flow.

As shown in Figure 5.3, surface water infiltration provides source water for the vadose zone, where the infiltration flux is defined from the difference between applied surface flux (i.e., rainfall) and runoff flux. The infiltrating water provides source water for either the perched zone or the saturated zone, where the water table elevations are indicated by the inverted solid triangles. The purpose of the vadose and perched water flow solutions is to provide boundary data for the saturated zone flow model. That is, the water flux entering the saturated zone from above is incorporated by applying the estimated flux values to the top layer of the CTM.

Finally, Figure 5.3 shows how wells and surface watercourses (the Toms River in this case) are incorporated into the flow model. Each pumping well is associated with one or more model layers as per the well screen location. The Toms River is a surface expression of the aquifer (the groundwater becomes surface water and vise-versa), here shown as a source for groundwater in the top model layer.

Figure 5.4 provides a map-view of the extent of the flow model domain. Where practical, the boundary of the model is keyed into regional surface watercourses, and in general it is set far from the area of interest (i.e., the extent of groundwater contamination in and around the Site).

Table 5.1 provides a summary of the CTM's flow model input requirements and the resulting output information.

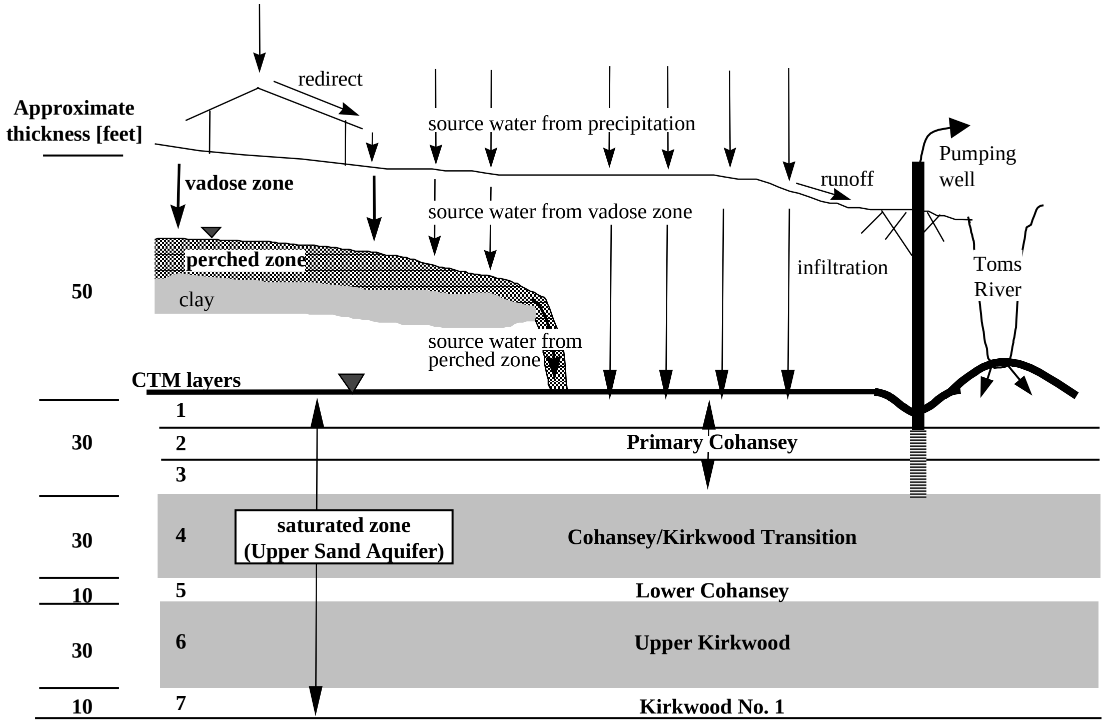

Figure 5.3 - A conceptualized cross sectional view through the CTM domain (not to scale). The CTM models the Upper Sand Aquifer using seven 'layers,' where the top three represent the Primary Cohansey. The influence of vadose and perched water flux on saturated zone flow is incorporated by estimating the water flux associated with the vadose and perched zones and applying it to the top model layer (layer 1). The Toms River is shown here as a source of water to the top model layer. Pumping wells are associated with unique model layers, in this case the well is screened in layers 2 and 3.

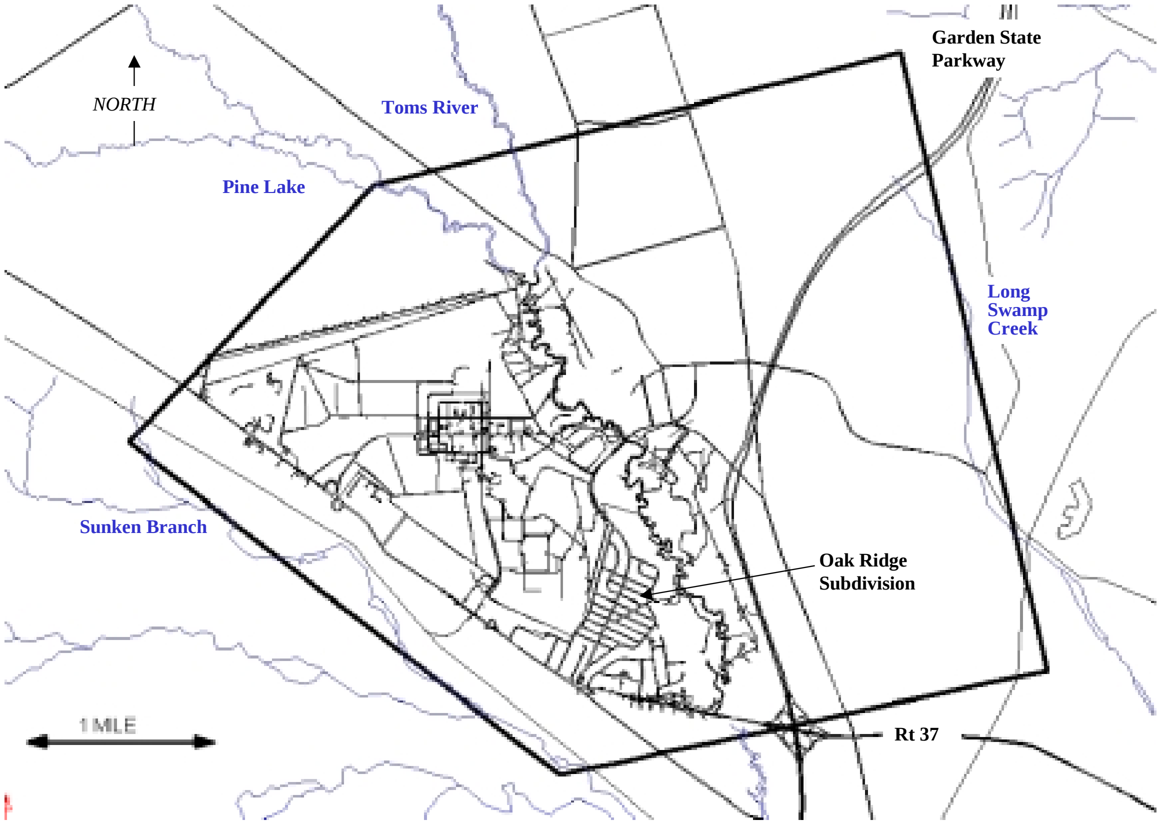

Figure 5.4 – The horizontal extent of the groundwater flow model (heavy-lined polygon). Where practical, the boundary of the model is keyed into regional surface watercourses, and, in general, it is set far from the area of interest. In the vertical dimension, the flow model includes the Upper sand aquifer.

Table 5.1 - Summary of the components of the flow model, their data support and computational output

FLOW ZONE	CTM INPUT PARAMETERS AND DATABASE SUPPORT	CTM RESULTS
Vadose	• precipitation records • river gauging records • topography • surface features (history) • recharge area history	• time- and space-averaged infiltration flux rate
Perched	• source water from vadose zone • water level monitoring data • topography of clay unit • continuity of clay unit	• spill-off point locations • flow rate at each spill-off point • time history of water table elevation
Saturated	• location and magnitude of source water from vadose zone • location and magnitude of source water from perched zone • soil properties: hydraulic conductivity and porosity • water level monitoring data • time-history of pumping well data • river gauging records	• water velocity magnitude and direction in the Upper Sand Aquifer • time history of water head elevation in the Upper Sand Aquifer

5.3.1.1 Flow Model Calibration

The goal of flow model calibration is to verify that the flow components of the CTM are accurately represented for use in the contaminant source and transport model. In this context, the important calibration (fitting) parameters include the temporal and spatial distribution of the boundary conditions as predicted by the vadose and perched zone components, and the spatial distribution of the hydraulic conductivity. Note, hydraulic conductivity is a parameter that defines the relative ease with which water will flow through a particular soil. For example, it is relatively difficult to push water through clay and easy to push water through sand.

Calibration is achieved by altering model input parameters so that the model matches measured groundwater elevation data (observed water levels in monitor wells). The groundwater elevation data, as measured in monitor wells, is a measure of the water pressure in the aquifer. This pressure, called *head*, provides information on water movement, because water will flow from a point of high head to a point of low head.

In general, to assess calibration results we ask two basic questions:

1. Does the model predict the correct groundwater elevation at discrete points (monitor wells) and at multiple times? This question confirms the quality that the model predicts the correct response of the aquifer to changing flow stresses (i.e., rainfall, river stage, pumping wells).
2. Does the model predict the correct slope of the groundwater head? This is the same as asking, does the model predict the correct direction and magnitude of groundwater flow? This question is of particular importance when assessing whether the flow model is acceptable for use in contaminant transport modeling.

With respect to answering question 1 above, consider the calibration results presented in Figures 5.5. These Figures show a time trend comparison of model to data for several monitor wells in the northern (Figure 5.5a) and southern (Figure 5.5b) portions of the site. The data spans a time frame from between 12 and 22 years depending on the well. From these figures the following qualitative conclusions can be drawn:

1. The model does a good job at predicting the time trend in groundwater elevation. The time variation is predominantly caused by the variability in rainfall and the operation of pumping wells.
2. While at any one point in time, the difference in model prediction and data can be on the order of several feet, the average difference is relatively close (on the order of one foot).

With respect to answering question 2 above, i.e., does the model predict the correct direction and magnitude of groundwater flow, consider the calibration results presented in Figures 5.6. Each of these figures shows two groundwater head cross-sections through the Primary Cohansey in different portions of the Site. They compare observed and model-predicted data at two hydrologically different times, i.e., before the Groundwater Extraction and Recharge System (GERS) was implemented and after GERS implementation. From these figures the following qualitative conclusions can be drawn:

1. The model correctly reproduces the slope of the groundwater head both before and after GERS operation (two significantly different flow regimes).
2. While the magnitude of the head may not be the same at individual points (i.e., the post GERS plots), the slope is correctly predicted.

Additional details of the flow model setup and calibration results are provided in the Final Modeling Studies Report, Chapter 1, Section 7.1 and Chapter 1, Appendix D (Ciba 1998c). Also, additional information on the cross-section analysis presented here can be found in the Site-Wide Monitoring Program (SWMP) of the Long-Term Monitoring Program (LTMP) Report (Ciba 1999a).

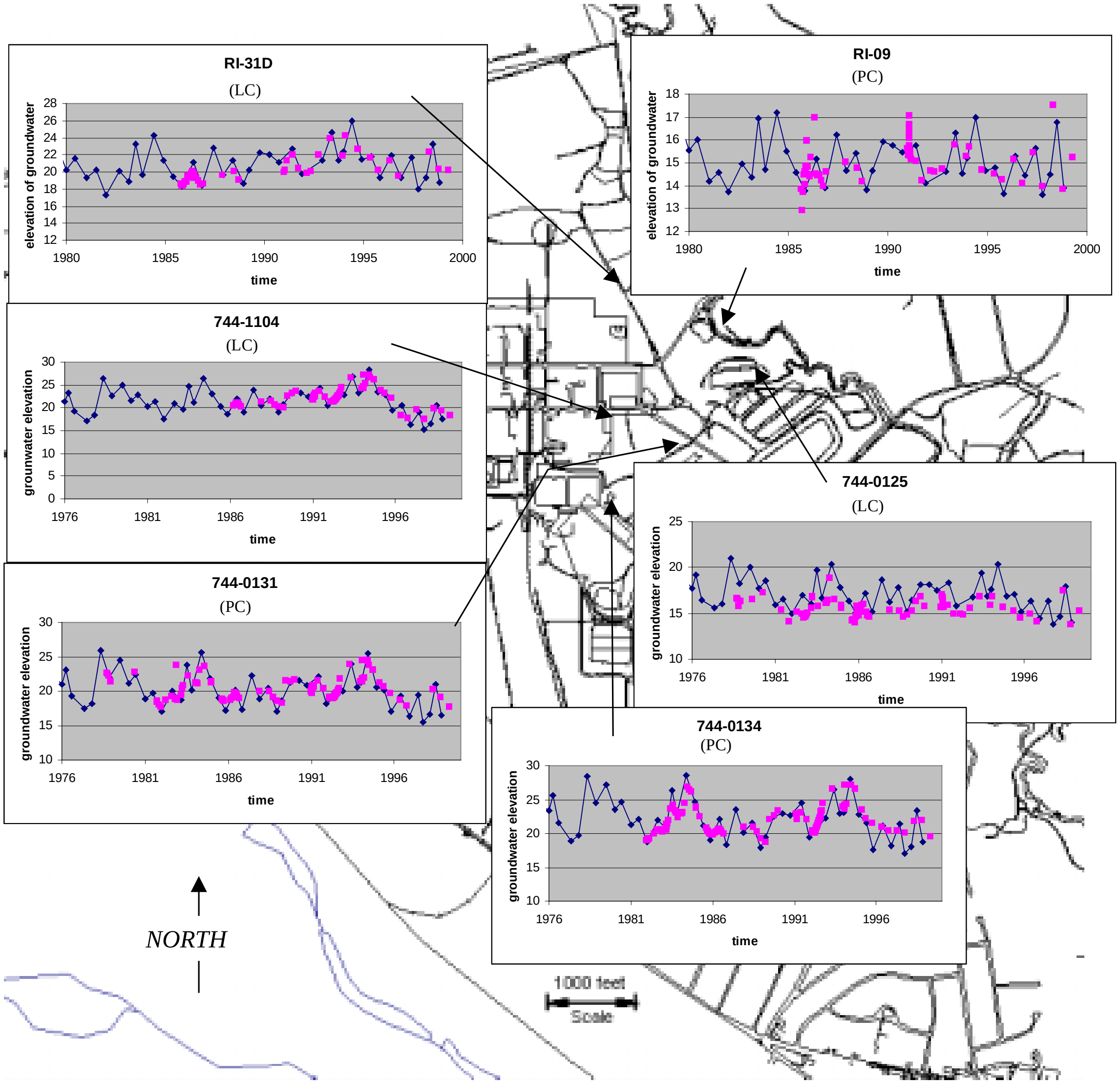

Figure 5.5a – Comparison of predicted CTM groundwater elevations (connected diamonds) to measured data (unconnected squares) at six monitor wells in the northern section of the site. The abbreviation PC = Primary Cohansey and LC = Lower Cohansey.

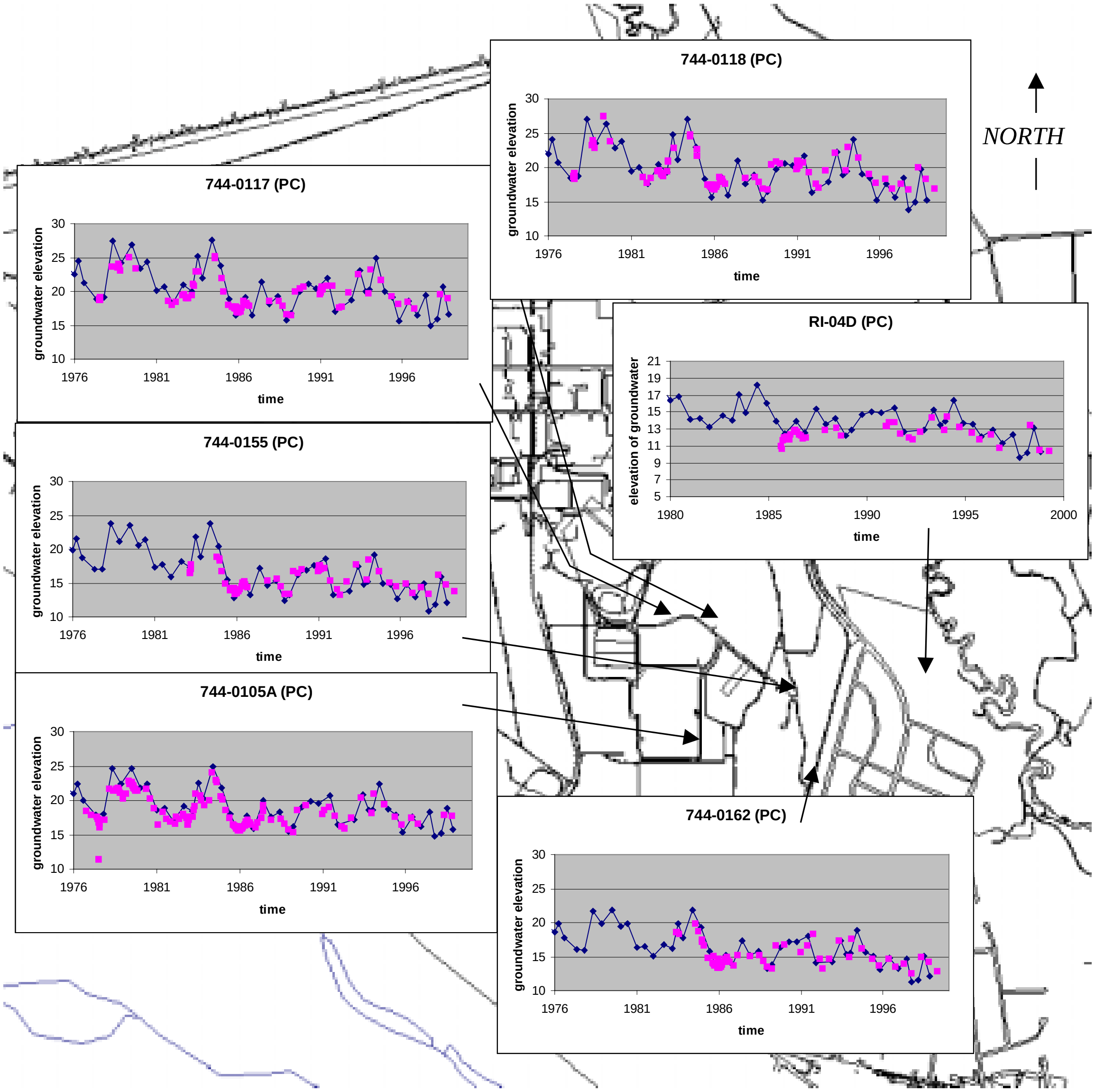

Figure 5.5b – Comparison of predicted CTM groundwater elevations (connected diamonds) to measured data (unconnected squares) at six monitor wells in the southern section of the site. The abbreviation PC = Primary Cohansey.

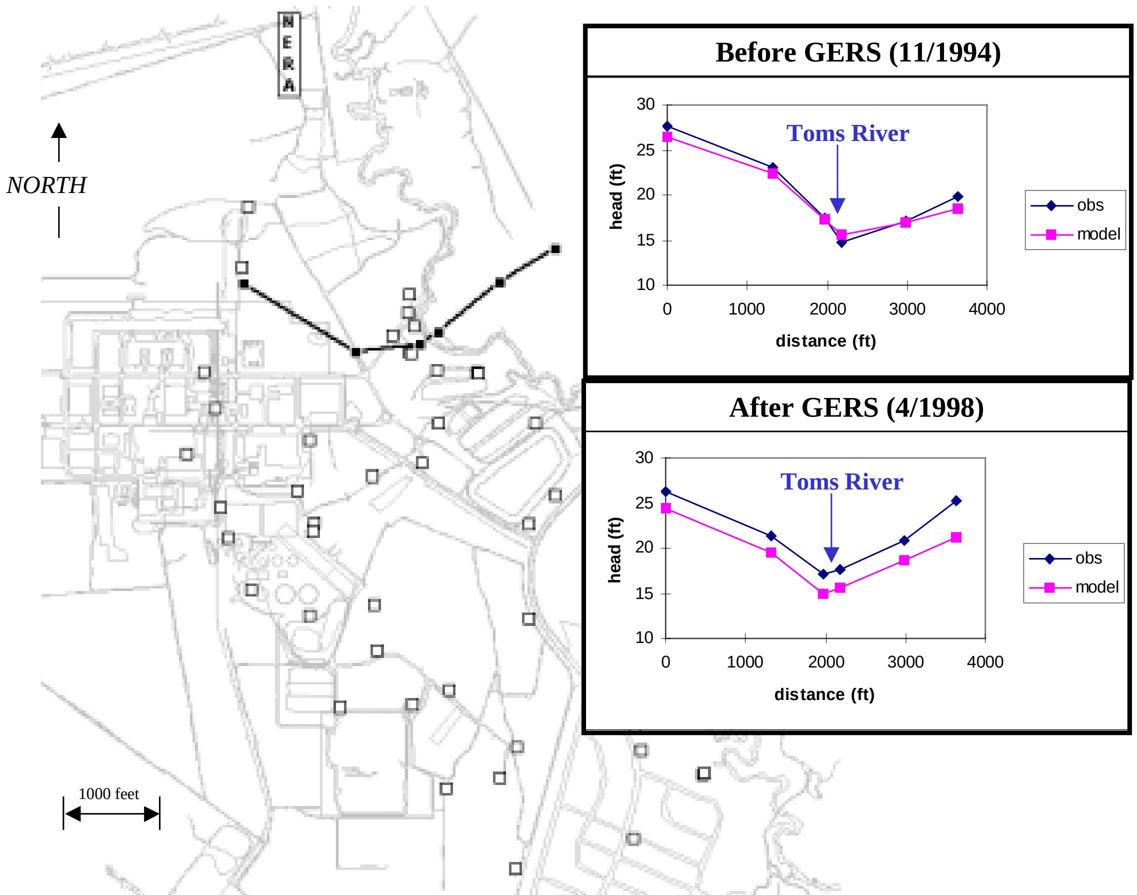

Figure 5.6a – Flow model calibration results for a cross-section through the Primary Cohansey in the northern part of the Site. Each black square on the map connected by the black line represents a monitor well screened in the Primary Cohansey. The plots to the right show the observed and model-predicted shape of the groundwater head along the line (as inferred from point-wise elevations) at two different times (before GERS operation, and after GERS operation). The open squares on the map represent the location of a GERS well, and NERA stands for the northeast recharge area.

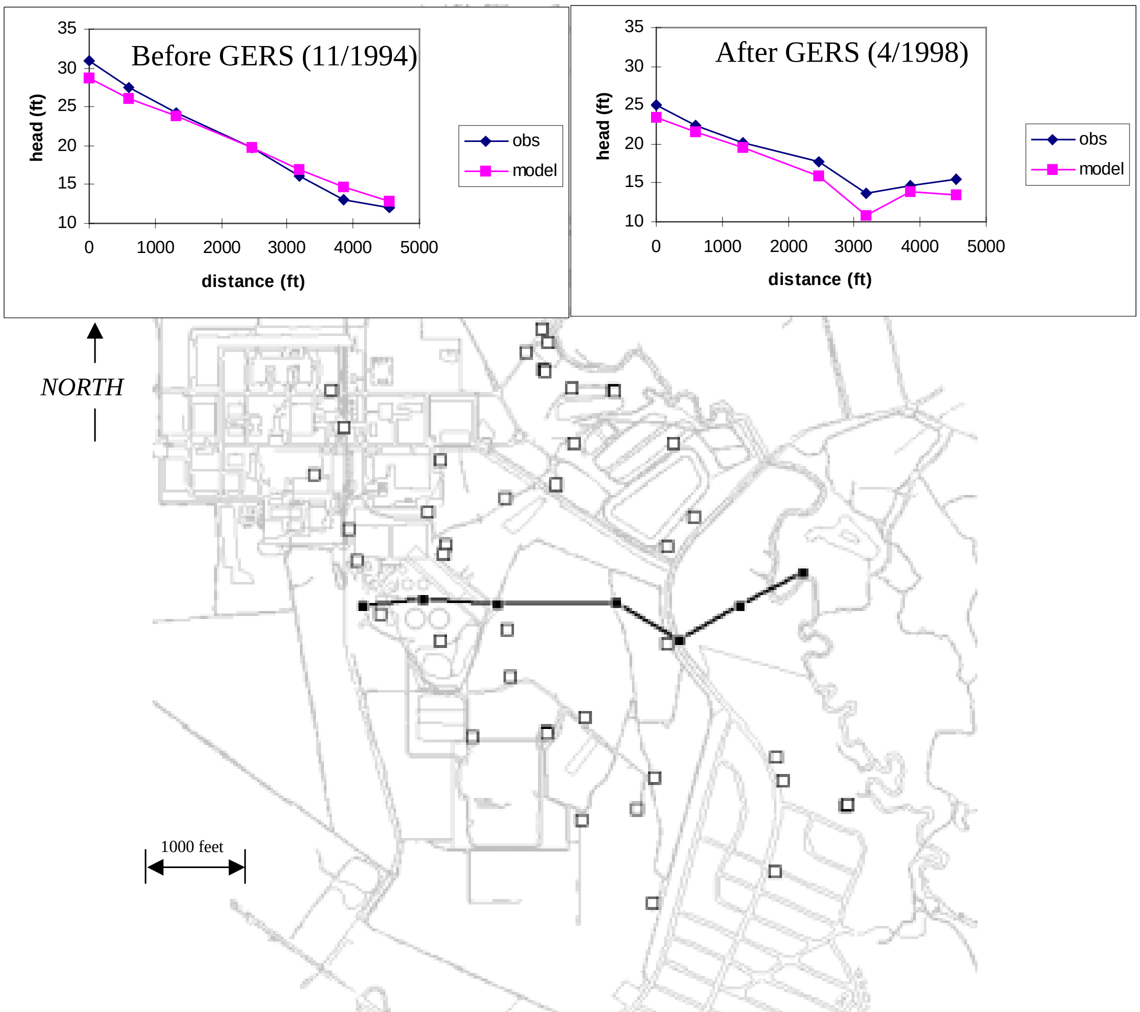

Figure 5.6b – Flow model calibration results for a cross-section through the Primary Cohansey in the middle part of the Site. Each black square on the map connected by the black line represents a monitor well screened in the Primary Cohansey. The plots at the top show the observed and model-predicted shape of the groundwater head along the line (as inferred from point-wise elevations) at two different times (before GERS operation, and after GERS operation). The open squares on the map represent the location of a GERS well.

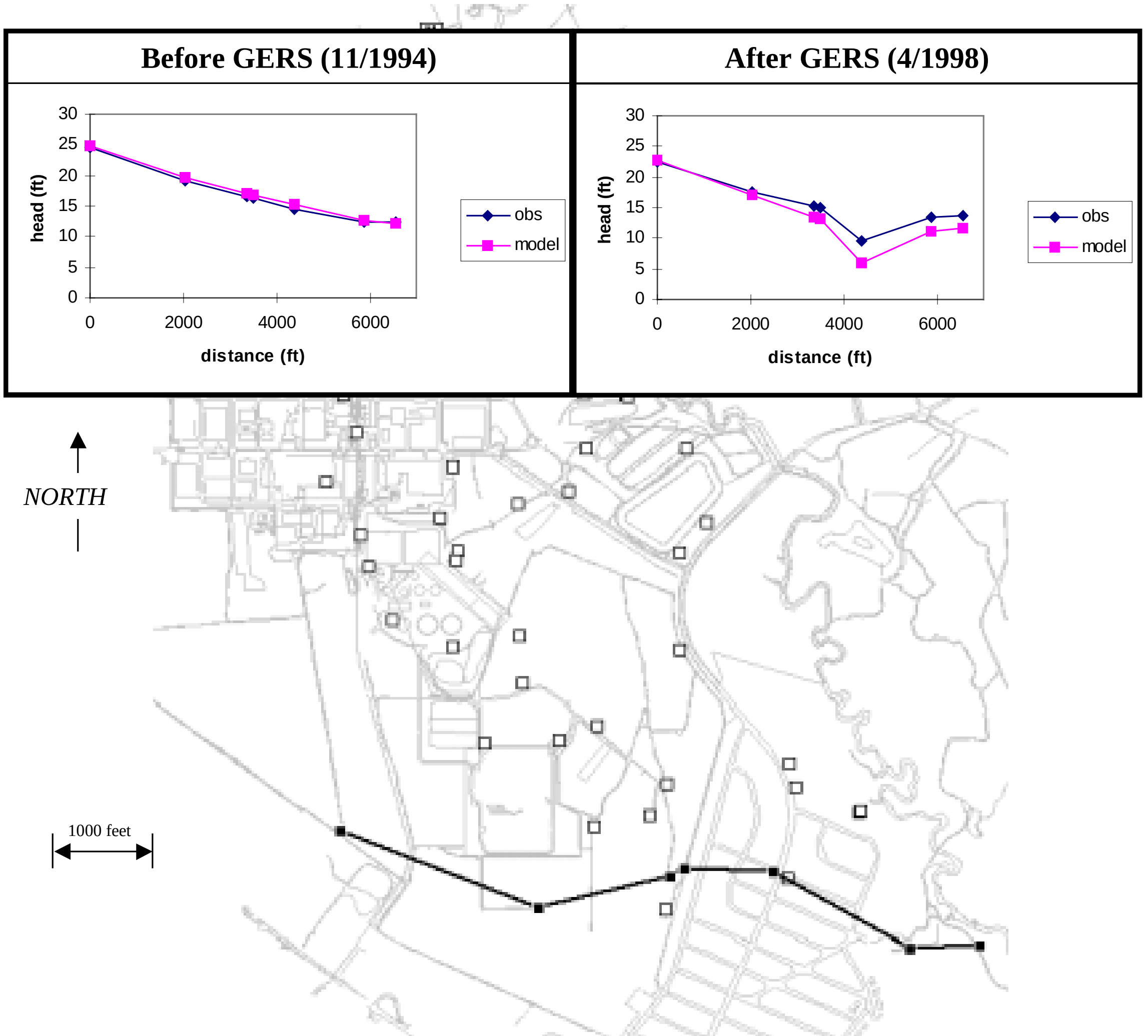

Figure 5.6c – Flow model calibration results for a cross-section through the Primary Cohansey in the southern part of the Site. Each black square on the map connected by the black line represents a monitor well screened in the Primary Cohansey. The plots at the top show the observed and model-predicted shape of the groundwater head along the line (as inferred from point-wise elevations) at two different times (before GERS operation, and after GERS operation). The open squares on the map represent the location of a GERS well.

5.3.2 THE CONTAMINANT SOURCE AND TRANSPORT MODEL

As stated earlier, the contaminant source and transport model defines the distribution of contaminants at the Site. The particular contaminants modeled include the nine COCs identified for the site (see Section 3.1).

For the purposes of this development, consider that the *source* part of the model defines locations for the sources for groundwater contamination and how the contaminant mass gets into the aquifer. The *transport* part of the model defines contaminant mass distribution within the aquifer over time.

In this section, we will provide an overview of the conceptual model that represents the contaminant source and transport conditions at the Site. This will be achieved by first developing the conceptual model for the source conditions, and then developing the conceptual model for the transport conditions. After developing the conceptual models, examples of the model calibration results are presented.

5.3.2.1 Source Model

The source model is based on the conceptual premise that the following conditions hold:

1. Contamination in the characterized source areas (refer to Section 3.4) is responsible for most of the groundwater contamination at the Site. That is, it is assumed that site-wide aquifer restoration can be achieved by remediating the source areas described in Section 3.4.
2. Contamination is transferred from the source area to the aquifer as a dissolved component in flowing groundwater. That is, the only way for contaminants to get from the source area to the aquifer is to first dissolve into the groundwater that is migrating through the source.

From condition 2 above, in order to be clear on meaning, let us define a source model parameter, namely the *dissolved mass-loading rate*. The dissolved mass-loading rate is the rate that dissolved mass leaves the source and enters the aquifer. The term *leachate* is also used to describe water that has become contaminated after having migrated through a source and "leached" dissolved mass.

In Section 3.4 we detailed the source area characterization database. As discussed in Appendix D [see also the Final Modeling Studies Report, Chapter 1, Section 7.2 (Ciba 1998c)] Toms River Site, Operable Unit 2, October 1998, Chapter 1, Section 7.2), the database is analyzed and the individual source areas are "sectioned" into one or more source model work blocks. A work block represents a unique part of a particular source area where the dissolved mass loading behavior can be effectively estimated. The location and size of each work block is defined based on its physical attributes. These attributes include chemical composition and hydrological and geological setting. The goal is to idealize each source area into zones where similar dissolved mass loading behavior is expected. This concept is developed in more detail below.

Given this characterization, the source model is used to answer the following questions regarding each work block:

1. Given an estimate of how much water flow through the block, how much chemical dissolves into that water? In other words, what is the dissolved mass loading rate, and how does it change with time?

2. Where does this contamination enter the aquifer?

In order to answer the first question we apply a "cause-and-effect" model. That is, we develop a model that relates work block physical attributes (i.e., soil and chemical distributions within the block) to principles of chemistry (i.e., how chemical mixtures dissolve in water) and groundwater flow dynamics (i.e., how groundwater flows through the block). In simplified terms the model provides estimates for the following:

1. <u>Groundwater flow through the block</u> (as per the flow model).

2. <u>The contaminant mass "partitioning efficiency.</u>" That is, the efficiency with which work block contaminant mass dissolves (partitions) into the water that is flowing through it. For example, consider that, in general, work block contaminant mass is not evenly distributed. In this case, some water that flows through the block may not actually contact contamination, and therefore, pass through virtually clean. At the other end of the spectrum, water that flows through a contaminated zone may partition the maximum concentration (i.e., the equilibrium solubility limit).

3. <u>The concentration of the modeled chemicals in the leachate</u> (i.e., each of the COCs). This is based on an empirical model (called Raoult's Law) that defines the solubility of a particular chemical in water as a function of the mixture of chemicals in the work block. Specifically, the solubility of each chemical in a mixture is depressed relative to its pure phase value. For example, the pure phase solubility of chlorobenzene in water is 500 ppm, and for a 50-50 mixture by weight of chlorobenzene and trichloroethene, the solubility of chlorobenzene is 270 ppm. (chlorobenzene must 'share' the water with trichloroethene according to a mixing rule called Raoult's Law).

4. <u>The change in the mass loading rate with time.</u> Time variability is built into the model by considering time-varying groundwater flow conditions (as per the flow model) and a relation between partition efficiency and total contaminant mass remaining in the block.

An important attribute associated with the source model is that *a unique partitioning efficiency is computed for each work block*. Based on the assumption that the mixture of chemicals within the work block is uniform, this partitioning efficiency is applied to all the chemicals being modeled (i.e., the COCs). The result is that given an estimate of the water flow, chemical content, and partitioning efficiency for the work block, the dissolved mass loading rate can be computed for all the chemicals of interest. Table 5.2 summarizes the major assumptions used in the source model to define the dissolved mass loading rate, their purpose, and their effects on model predictions.

Table 5.2 – Summary of the major source model assumptions that go into the estimation of the dissolved mass loading rate for each of the COCs, and their effect on CTM prediction.

Assumption	purpose	Affect on prediction
Uniform chemical mixture within the block	Allows a single partitioning efficiency to be computed for each block. This makes the source model computationally feasible.	Magnitude of the concentration of each modeled chemical in the leachate
Solubility of each COC in water is a function of the composition of the mixture in the work block.	Along with partition efficiency, allows the dissolved concentration in the leachate to be computed	Magnitude of the concentration of each modeled chemical in the leachate
Partition efficiency is a function of block geology and chemical content.	Couples the leaching process to physical properties and allows partition efficient to change with changing work block contaminant mass.	Time trend in concentration of each modeled chemical in the leachate. If the efficiency is estimated low, the predicted trend will be milder than observed. The contrary is also true.
Total chemical mass in each block is known from geostatistical characterization of soil data.	Used to define the solubility of each COC in water.	Time trend in concentration of each modeled chemical in the leachate. If the total mass is estimated high, the predicted trend will be milder than observed. The contrary is also true.

The work block characterization is used to provide the necessary estimates as outlined above, specifically:

1. Geometry – defines volume and orientation to groundwater flow.

2. Chemical content - defines the quantity of chemical present in the block, which in turn is used to define the uniform chemical makeup of the leachate (i.e., the concentration of each of the nine COCs). Also used to assess how efficiently groundwater, percolating through the source, picks up dissolved contaminant mass.

3. Flow zone location – Used to estimate the groundwater flow conditions through the block. Figure 5.7 illustrates the concept that at the Site each working block can be classified as residing in one of three flow zones.

    - Vadose-zone - the work block is located above the water table (above the aquifer). The flow rate is estimated based on the infiltration rate computed from the flow model.

    - Intermittent contact (IC)-zone - the work block is located between the high- and low-water table. For example, Figure 5.5 shows that seasonally the elevation of the groundwater can vary 5 – 10 feet. In this case the saturated thickness of the block is a variable function of the elevation of the water table. The flow rate is then defined in terms of the saturated thickness, where in general the flow rate increases as the work block saturated thickness increases. The elevation of the water table is determined directly from the water level and precipitation database.

    - Saturated-zone - the work block is located below the water table and is therefore always liquid saturated. In this case the flow rate is related to the ambient groundwater flow conditions, soil diversity, and the distribution of the contamination within the work block.

4. Soil properties – The type(s) of soils and their distribution within the block. Used to assess how much water flows through the work block, and the efficiency with which that water picks up contaminant mass.

Given an estimate of the *dissolved mass loading rate* from each work block, the next step is to determine where this contaminant mass enters the aquifer. This determination is based on a qualitative, integrated, interpretation of the following data:

1. Water Quality Data – This data includes many discrete locations in and around the Upper Sand Aquifer where groundwater quality has been measured at one or more times in the past. From this database, the structure of the contaminant plume is inferred. For example, we are particularly interested in where the plume is, and isn't, and where the zones of highest concentration are located.
2. Groundwater Flow Data – This data includes both monitor well measurements and CTM flow model results. Understanding groundwater flow is of particular importance because it has the most influence on contaminant distribution throughout the aquifer.
3. Site geology – Figure 5.7 illustrates the importance of understanding site geology. Of the three work blocks represented in the figure, the "vadose" and the "saturated" blocks load their dissolved mass into the aquifer (the saturated zone) directly downstream of the block's exit point. However, due to the presence of an intervening clay layer (causing the presence of a "perched" flow zone), the "intermittent contact" block loads its mass to the aquifer at a displaced location. In this case, the edge of the clay layer. Note that this type of geologic influence can affect any work block.

To this point we have developed the contaminant source and transport model to where the source conditions are computable. Table 5.3 summarizes the source model parameters and their functional and data relationships.

Table 5.3 – Summary of the parameters that define the source terms for the transport model, and how they are estimated prior to calibration.

Work block parameter	Dependent variables	how estimated
Dissolved mass loading rate	• Water flow through block ∗ Partitioning efficiency ♦ Chemical concentration	• block geometry and geology • groundwater head data • flow model results ∗ total amount of chemical mass in block ∗ block geology ♦ geostatistical characterization ♦ chemical mixture theory
Dissolved mass entry point to aquifer		• Aquifer characterization: Contaminant plume location, Groundwater flow direction, Geology.

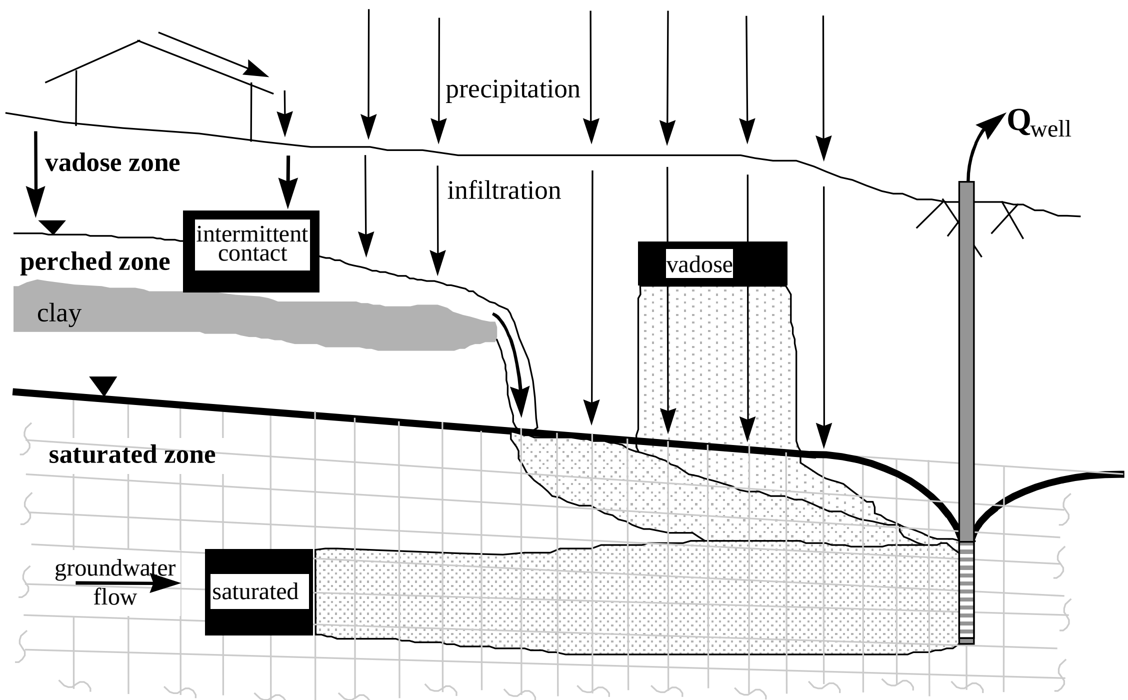

Figure 5.7 – An illustrative example of the three flow zones with which a work block can be associated. This information is used to estimate the amount of water that percolates through a work block. A vadose zone work block is always liquid unsaturated and the flow rate is estimated based on infiltration computations. An intermittent contact work block is affected by a fluctuating water table and the flow rate is defined in terms of the water table elevation. A saturated zone work block is always liquid saturated, and water flux through the source is a function of the groundwater flow rate.

5.3.2.2 Transport Model

The transport model defines the geometry of the plumes (zones of contaminated groundwater) that emanate from the contaminant mass entry points (as defined from the source model). It solves a contaminant "mass balance" equation to determine the contaminant mass distribution over time throughout the aquifer. Simply stated, mass balance requires that the amount of contaminant mass that is in the aquifer at a given time is equal to the amount of mass that has entered previously, *minus* the amount of mass that has either left or been destroyed.

To solve the mass balance equation, the transport model uses a "discrete" representation of the aquifer. That is, the aquifer is idealized as an assemblage of interconnected blocks (similar to the blocks used in the source model). Each block is on the order of 2000 cubic yards of aquifer. The contaminant mass is transported from block to block over time. The solution that the transport model provides is the mass associated with each aquifer block as a function of time. Given this information and the finite volume of each aquifer block, the contaminant "concentration" can be computed (i.e., parts of contaminant per million parts of water [ppm] in the block). *The important conclusion to be drawn here is that the CTM provides us with an estimate of the average concentration associated with a finite volume of aquifer*.

As with the flow model, the transport model includes the Upper Sand Aquifer in its computational domain (illustrated in Figure 5.3). The lateral boundary of the transport model computational domain is shown in Figure 5.8. Note that this is smaller than the flow model domain (Figure 5.4), as the contaminant distribution problem is confined to a smaller volume of aquifer.

The important model attributes that define contaminant transport include:

1. <u>Ground water velocity magnitude and direction</u> - This information defines the 'advective' component of mass transport; it is time- and space-dependent; and it is defined from the calibrated flow model as described in Section 5.2.1.
2. <u>Horizontal and vertical components of dispersivity</u> - These parameters, in conjunction with ground water velocity parameters, define the 'dispersive' component of mass transport. The coefficients of dispersivity account for contaminant plume *spreading* and *mass dilution* as the result of flow and transport processes that occur at a smaller spatial scale than that represented by the model (i.e., flow channeling and mixing effects caused by small-scale irregularities within the aquifer sediments). Their magnitude is related to Site geology. These coefficients are estimated through sensitivity analysis of a literature-based range (as they relate to Site geology).
3. <u>Retardation coefficient</u> - This coefficient defines the relative propensity for a particular contaminant to temporarily stick to the aquifer soils as it is migrating away from the source. This phenomenon

effectively slows down the overall transport dynamic. A study was performed at the site [the "K_d Study Report (Ciba 1998c)] in order to quantify this parameter. It was found that this Site has relatively low retardation properties.

4. Biodegradation coefficient – This parameter accounts for contaminant mass loss within the plume due to biological degradation. A site-specific study was performed (see Appendix F), and it was found that degradation is occurring at the Site at a slow but meaningful rate.

Table 5.4 provides a summary of the CTM contaminant transport model data input requirements and the resulting output information.

At this point CTM conceptual development is complete in the sense that all the computational components are in place, i.e., groundwater flow, contaminant source loading and contaminant transport. The next step is to verify, through calibration, that this model is an appropriate analysis tool. Model calibration is the focus of the next section.

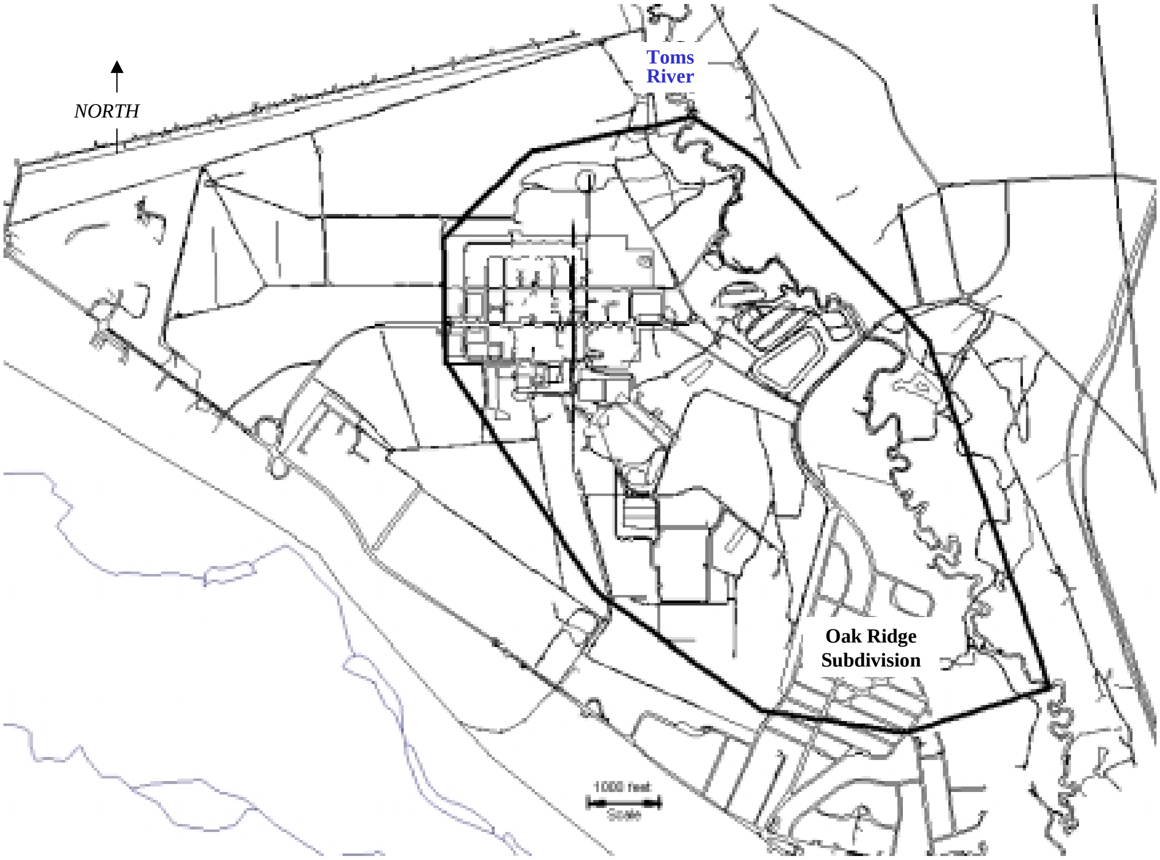

Figure 5.8 – Map of the lateral extent of the contaminant transport model, the heavy-lined polygon.

Table 5.4 - Identify transport model parameter set and how they are estimated prior to calibration.

Parameter group	parameter	variability	how estimated
Mass balance (i.e., what is in the aquifer must equal the difference between what enters and what leaves)	• ground water velocity magnitude and direction * components of dispersivity retardation • biodegradation	• time and space * space space • space	• saturated zone flow model * sensitivity analysis of literature value-based range K_d -Study report, field data, sensitivity analysis[1] • Intrinsic Bioremediation Report results
Boundary and external forcing conditions	Dissolved mass loading rate	time and space	Source Model (Table 5.3)
initial conditions	Initial concentration of each COC throughout the site	space	• Before the plant was established at the Site, the aquifer was clean • To model from current conditions forward, interpret the plume from water quality data.

[1] See "Sensitivity Analysis Technical Memorandum" (Ciba 1998i) for details.

5.3.2.3 Calibration

The purpose of CTM calibration is to

- Verify the conceptual model developed for the Site (Are all the important physical processes controlling aquifer behavior understood/represented); and
- Reduce the uncertainty of those model parameters that affect decision making (Given that the CTM is "estimating" aquifer behavior, how can we ensure that the estimates provide an appropriate basis for decision making?).

With respect to the second bullet, let us review the CTM's role in decision making. That is, the CTM is used to help quantify the following decision variables:

1. The level of work block remediation required to realize groundwater restoration goals.
2. The appropriate time frame in which the aquifer restoration standards must be met.

If we relate work block remediation to a reduction in its contaminant mass loading rate, then the problem can be posed in terms of CTM parameters, and the CTM can then provide decision-making support. For example, given the modeled mass-loading behavior of each of the work blocks identified for the site under different remediation scenarios, the CTM provides a prediction of the resulting groundwater concentration throughout the aquifer at different times in the future. Table 5.5 summarizes the relationship between CTM parameter magnitude and the concentration solution (C) at a point in the aquifer at a particular time. Note that aquifer restoration leads directly from source area remediation, because source remediation reduces the dissolved mass loading rate which in turn reduces contaminant concentrations in groundwater.

Based on this discussion, in order for the CTM to have utility during the FS, we need to verify, through calibration, that it can perform the following tasks:

1. Quantify the current dissolved mass loading rate for each work block. This provides a basis upon which to prioritize remediation efforts.
2. Predict the future work block dissolved mass loading rate under different remediation scenarios. That is, predict how the dissolved mass loading rate attenuates over time due to remediation efforts and natural source depletion processes.
3. Predict the current and future source impact to groundwater. That is, predict the relation between the dissolved mass loading rate from work blocks and groundwater quality.

Recall that calibration involves adjusting model input parameters so that model predictions match available field data. In this case, the available field data consists of groundwater quality measurements taken at different points in the Upper Sand Aquifer (i.e., monitor and pumping wells). Each monitor point has been sampled for COCs one or more times from early 1985 to the present. The point-wise data provides a measure of plume distribution at a given point in time, and the time variability associated with the data at individual points provides a measure of evolutionary trends in plume development. This database is assumed appropriate for CTM calibration for the following reasons:

1. As Table 5.5 shows, groundwater quality is directly related to source conditions. Therefore, unless source conditions are correctly interpreted, calibration based on groundwater quality data cannot be achieved.
2. The availability of time trend data is used to support the source model's interpretation of how the dissolved mass loading rate changes with time. That is, the assumption is made that if the CTM effectively recreates observed water quality trends in the past, then the source model's definition of how the dissolved mass loading rate changes with time has been verified. As shown in Table 5.6, the magnitude of the mass loading rate is directly related to the total contaminant mass in the block and the groundwater flow rate through the block.

Table 5.5 – Summary of the relationship between CTM parameter magnitude and the predicted concentration in the aquifer at a particular point and time.

Sub-model	parameter	how it affects CTM concentration solution (C) at a point in the aquifer at a particular time
Source	dissolved mass loading rate (DML)	as DML decreases C decreases
Source	source location	assessed with groundwater flow direction, as the point becomes aligned, C increases
Transport	flow direction	assessed with source location, as the point becomes aligned, C increases
Transport	flow magnitude	Defines "advective transport" and thus affects how fast the contamination moves from the source to the point of interest. Also, as magnitude increases, mixing is enhanced and C decreases
Transport	dispersion	Defines "dispersive transport," as magnitude increases, mixing is enhanced and C decreases
Transport	biological decay	as magnitude increases, more mass is destroyed and C decreases
Transport	retardation	affects how fast the contamination moves from the source to the point of interest

Table 5.6 – Summary of time-dependence associated with CTM parameters.

Sub-model	parameter	modeled time-dependence
Source	dissolved mass loading rate (DML)	♦ as block mass decreases (either through remediation or natural attenuation), DML decreases ♦ as flow through block decreases, DML decreases
Source	source location	Assume no change with time
Transport	flow direction	Varies mainly as a function of the time variability of pumping well location and extraction rate
Transport	flow magnitude	Varies mainly as a function of the timing of pumping well location and extraction rate
Transport	dispersion	Directly related to flow magnitude
Transport	biological decay	Assume no change with time
Transport	retardation	Assume no change with time

Before presenting the calibration results for the Site, let us first discuss an important groundwater flow feature, one that, to some extent, simplifies the calibration analysis. Figure 5.9 shows that there is a natural *groundwater flow divide* that effectively splits the site-wide contaminant plume into two sub-plumes: the so-called north and south plumes. The flow model was used to generate the head contours and flow paths shown. The results are representative of the Primary Cohansey under average natural conditions (no pumping wells active in Site).

This flow condition allows us to analyze each plume separately, because the plumes have no meaningful influence on each other. Calibration results and interpretation are presented first for the South plume and then for the North plume.

5.3.2.3.1 South Plume Calibration

The South plume is of particular interest to Ciba because it extends off the Site under the Oak Ridge Subdivision.

Before presenting and discussing the results of the calibration effort for the South plume, let us first discuss some of the important local attributes that have a significant effect on the distribution of contaminants in this part of the aquifer. These attributes include source location, geology (i.e., the layering of soils) and hydrology (i.e., the groundwater flow patterns).

With respect to the location of the sources contributing to south plume contaminant mass, as discussed in Section 3.3, there are two major source areas, namely:

- The Drum Disposal Area (DDA) [also contains the Standpipe Burner Area (SPB)], and
- The Filtercake Disposal Area (FCD) [also contains the Trench Disposal Area (TDA)].

Figure 5.10 provides a location map for these source areas.

Also in Figure 5.10, an important geologic feature is illustrated, that is, the distribution of the Yellow Clay unit. Note that both of the source areas are located above this intervening unit. As an illustrative example, Figure 5.11 provides a schematic of the effect that the clay layer has on DDA and FCD work block dissolved mass loading location. The clay not only redirects dissolved mass to its edge before entering the Primary Cohansey, but because of the presence of sand stringers (or lenses) within the clay, there are local entry points that "short circuit" the general trend.

As discussed previously, the dissolved mass entry points to the Primary Cohansey are determined from an assessment of geology-, hydrology-, and water quality-related data. The data used to assess South plume dissolved mass entry points is summarized in Table 5.7. The resulting dissolved mass entry points for the South plume are shown in Figure 5.15.

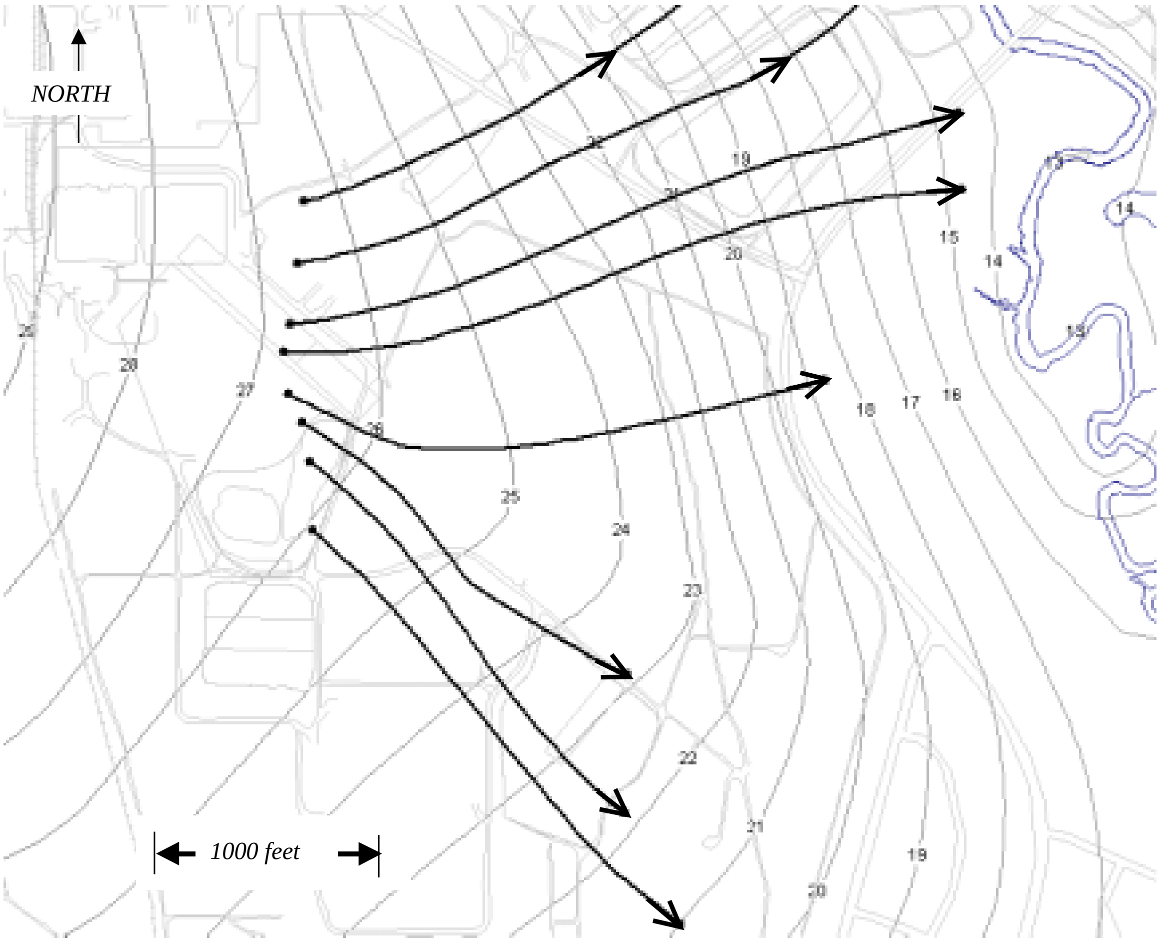

Figure 5.9 – Particle tracking analysis showing the existence of a natural groundwater flow divide at the Site. The heavy-lined arrows track the direction of groundwater flow in the Primary Cohansey under natural, average, flow conditions (no pumping wells active). The numbered contours represent the groundwater head in the Primary Cohansey (1 foot contour interval). The top four paths migrate towards the north keeping the north source contamination to the north. The bottom three paths migrate towards the south keeping the south source contamination to the south. This flow divide results in separate north and south plumes which are analyzed separately herein.

Table 5.7 – Summary of the data used to assess the dissolved mass loading entry points to the Primary Cohansey.

data	information support	time-related data	spatial coverage
Soil borings	▪ stratigraphy of the Upper Cohansey and Yellow Clay ▪ contamination in the soil	one-time data point	Figure 5.12
Monitor wells screened in the perched water system	▪ stratigraphy of the Upper Cohansey and Yellow Clay ▪ water quality of the perched system.	intermittent sampling for organic compounds 1985 through present.	Figure 5.13
Monitor wells screened in the Primary Cohansey	▪ stratigraphy of the Upper Cohansey, Yellow Clay, and Primary Cohansey ▪ water quality of the Primary Cohansey.	intermittent sampling for organic compounds 1985 through present.	Figure 5.14
Groundwater profiles - Direct Push Technology (DPT) points	▪ stratigraphy of the Upper Cohansey, Yellow Clay, and Primary Cohansey ▪ water quality of the perched system and Primary Cohansey.	one-time data point	Figure 5.15

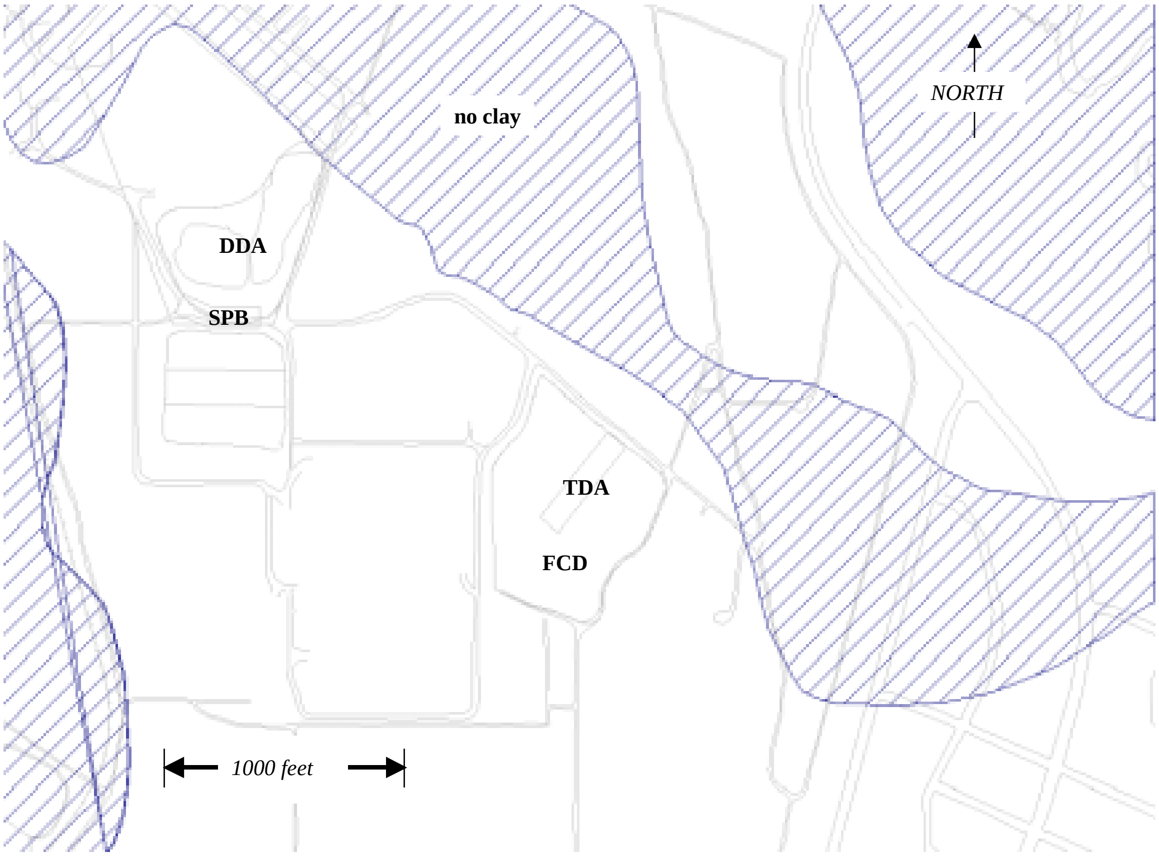

Figure 5.10 – Map view of the south plume source areas, the Drum Disposal Area (DDA), Standpipe Burner Area (SPB), Filtercake Disposal Area (FCD), and Trench Disposal Area (TDA). The cross-hatched areas indicate areas where the Yellow Clay is not present. All the source areas shown have an intervening clay unit between them and the Primary Cohansey (i.e., see Figure 5.11).

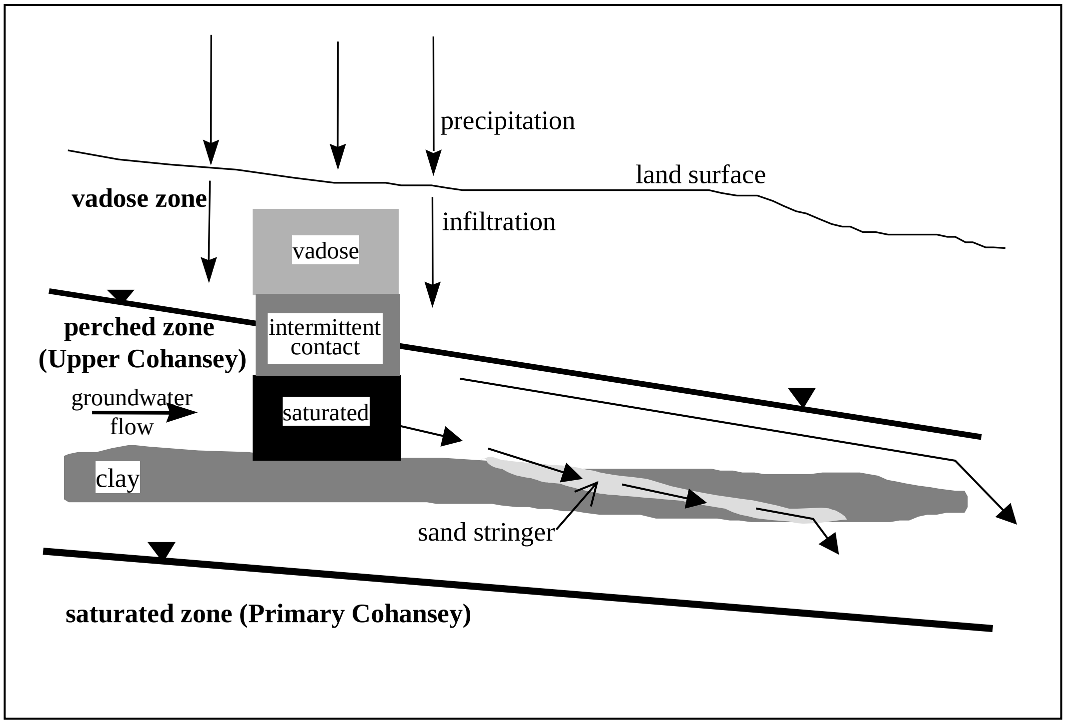

Figure 5.11 – Illustration of how leachate from the DDA and FCD work blocks makes its way into the Primary Cohansey. While the Yellow Clay supports a perched water table, it contains numerous sand stringers (lenses) that are able to transmit contaminated water to the aquifer. As shown, contaminated perched water can enter the Primary Cohansey in multiple locations "downstream" of the work blocks.

Figure 5.12 – Location map of the soil borings providing characterization data for the extent and continuity of the Yellow Clay (black dots). This data is used in part to determine the dissolved mass entry points to the Primary Cohansey.

Figure 5.13 – Location map of the monitor wells screened in the perched water system (black circles). The data from these wells provides characterization data for the extent and continuity of the Yellow Clay (boring logs), and perched water quality. This data is used in part to determine the dissolved mass entry points to the Primary Cohansey.

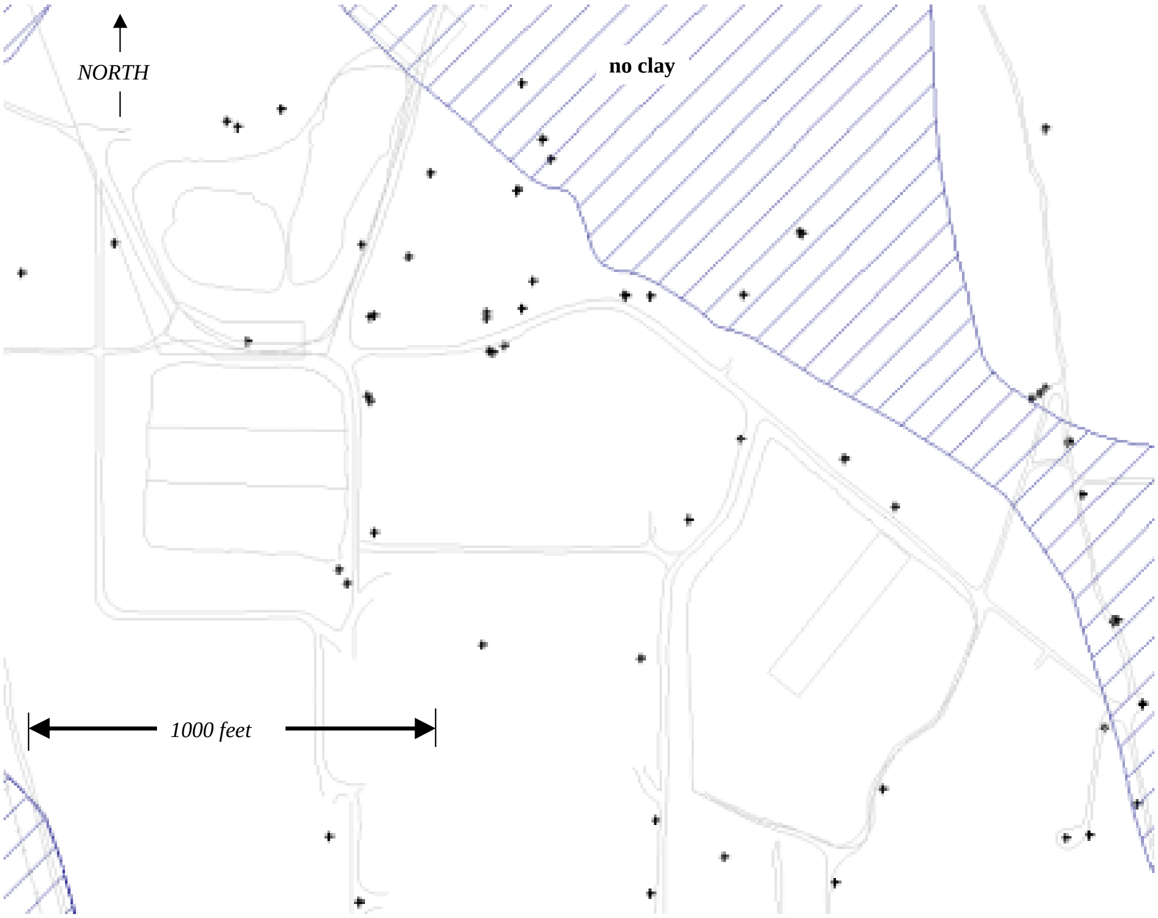

Figure 5.14 – Location map of the monitor wells screened in the Primary Cohansey (black crosses). The data from these wells provides characterization data for the extent and continuity of the Yellow Clay (boring logs), and water quality in the vicinity of source areas. This data is used in part to determine the dissolved mass entry points to the Primary Cohansey.

Figure 5.15 – Location map of the groundwater profile Direct Push Technology (DTP) data points (black triangles). In general these data points provide a vertical profile of geologic and water quality conditions through the Upper and Primary Cohansey. This data is used in part to determine the dissolved mass entry points to the Primary Cohansey.

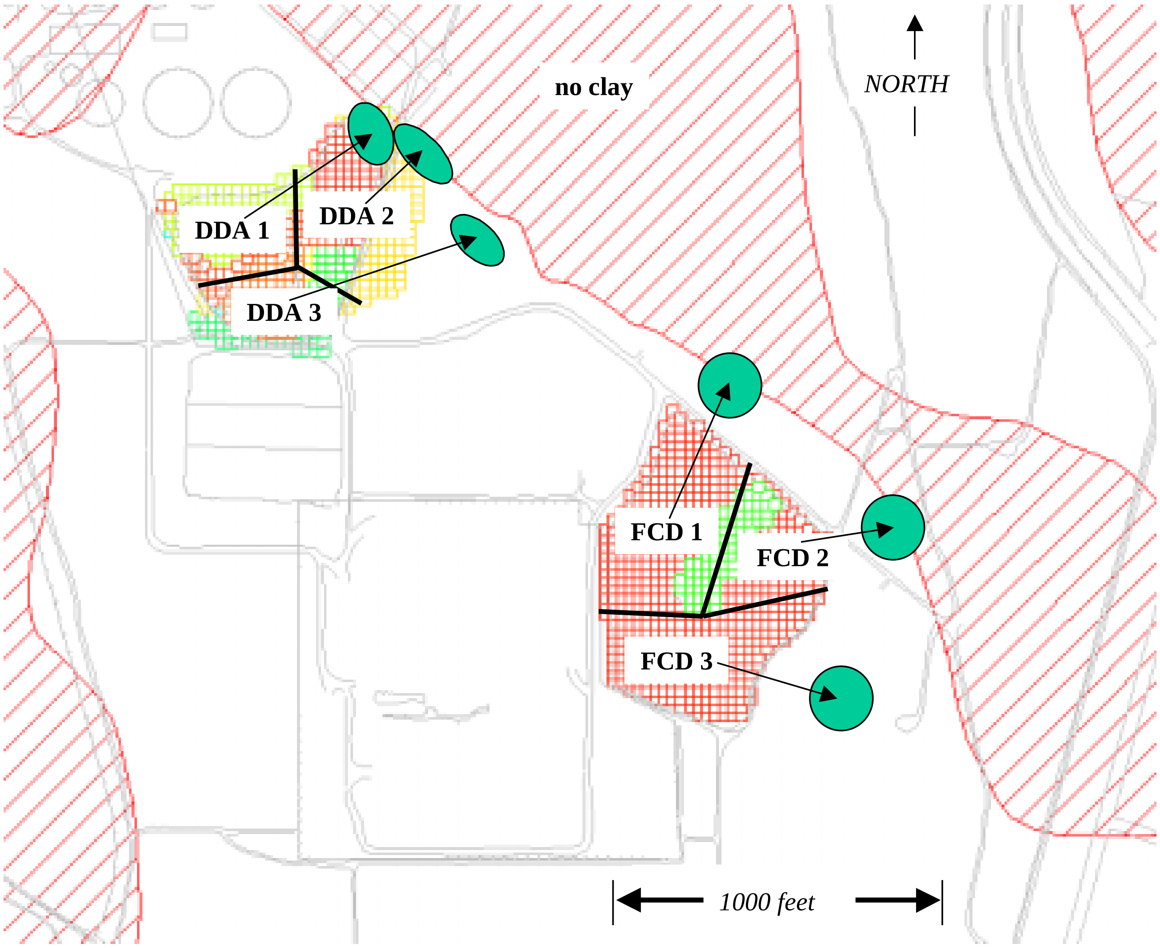

Figure 5.16 – Map view of the south plume source areas showing the approximate location of where the contaminant mass, leached from the work blocks, enters the top of the Primary Cohansey. Three loading locations (gray ovals at arrow heads) are assigned to each major source area, DDA and FCD. A zone within each source is assigned to one of the three locations, and work blocks are assigned one or two zones. The source area zoning and the spill locations were determined based on local groundwater flow, water quality and geology (as per the data summarized in Table 5.5).

An assessment of the historical trends in the groundwater flow patterns in the Primary Cohansey provides significant insight into the current distribution of contaminants in the South plume. There are three major flow patterns that have affected the plume since the source areas were active waste impoundment facilities (approximately 1953 through 1976, see Section 2 for details). The unique flow patterns are the direct result of different pumping well configurations. Consider the following description of the flow configurations that existed in the South part of the site from the 1950s to the present:

1. Pre-1985, no pumping wells operating in the South plume area. The CTM-modeled flow patterns in the Primary Cohansey are shown in Figure 5.16. The flow patterns indicate that after picking up contaminant mass from source areas, the groundwater flows generally south and east toward the Toms River which is a discharge point (that is, groundwater flows into the river).
2. 1/85 through 10/95 – operation of five pumping wells (called here the '85 purge wells) for the specific purpose of capturing the dissolved mass loading from the DDA and FCD. The location of the purge wells and the CTM-modeled flow patterns in the Primary Cohansey resulting from average pumping conditions are shown in Figure 5.17. Note that the flow patterns show capture of the groundwater that comes in contact with the source area contamination.
3. 10/95 to present – operation of the Groundwater Extraction and Recharge System (GERS). This system was implemented as part of the Operable Unit 1 remedy, and its intent is to capture the contaminant plume at the Site. Figure 5.18 shows the location of some of the GERS wells associated with the South plume. Also, this figure shows the CTM-modeled flow patterns generated as the result of average pumping conditions. Note that, as with the previous pumping configuration, the groundwater that comes in contact with the source areas is captured by the GERS wells.

There are two important implications associated with these groundwater flow results. The first is that, if correct, the South plume should show a decline in overall contaminant concentration with time in that part of the plume that is down-gradient of the capture wells. That is, because the pumping wells are intercepting the dissolved mass being loaded into the Primary Cohansey, the plume that is south and east of these wells should exhibit a general decline in concentration with time.

For example, consider the calibration results shown in Figures 5.19. The results are for two predominant COC compounds found in the South plume: chlorobenzene (Figure 5.19a) and trichloroethene (Figure 5.19b). The Figures indicate the location of the '85 purge wells and several Primary Cohansey monitor wells situated down-gradient of the purge wells. The plots show the observed and modeled concentrations with time since the wells were first monitored (early 1985) to present. The following conclusions can be drawn from these results:

1. The expected declining trend in concentration behavior is observed in both the measured and modeled data. This verifies that the flow model is providing an accurate representation of the groundwater flow patterns.

2. The CTM captures the declining trend in concentration with time. This attribute is most strongly affected by the groundwater flow solution.
3. In general, the CTM predicts the correct magnitude in concentration at points in time. The attribute of magnitude is most strongly affected by the CTM-predicted work block mass loading behavior previous to 1985. That is, the mass from the source areas had to get into the aquifer and be transported beyond the influence of the pumping wells before being recorded at the monitor points shown. Discrepancy in individual values of a factor of two or more is not unexpected. This is because the monitor point is sampling a volume of aquifer on the order of 10 cubic yards, while the CTM is providing an estimate for a volume on the order of 2000 cubic yards.

The second important implication of the flow model results shown in Figure 5.17 is that, during their operation, the ’85 purge wells captured virtually all of the dissolved mass being loaded into the Primary Cohansey from the South plume source areas. Note that in Figure 5.17 the flow paths converge on the well locations. This indicates that the contaminated groundwater associated with the flow paths is captured by the well and extracted from the aquifer.

This ‘local’ capture condition can be used to calibrate and verify CTM-related parameters. First, we note that the amount of contaminant mass extracted at a pumping well is equal to the well’s pumping rate times the concentration of contaminants in the extracted water. Recall from Table 5.4 that the concentration of contaminants in the aquifer is directly related to the dissolved mass loading rate (DML rate) assigned to each work block. Specifically, as the DML rate increases, the concentration in the aquifer increases, and vise-versa. Therefore, in order for the CTM to match the pumping well’s water quality data, the DML rate must be correctly prescribed. In this sense, the ’85 purge well database (flow rate and water quality) provides a ten year record of the DML rate from the South plume source areas which can be compared directly to CTM predictions.

Second, because of the close proximity of the ’85 purge wells to the source areas, some of the transport parameters listed in Table 5.4 do not play a major role in this analysis, i.e., dispersion, biodegradation, retardation, and the speed of groundwater movement. This is because the space and time scales associated with getting mass from the source to the pumping well are relatively short, and the importance of these parameters decreases as these scales decrease. For example, biological processes need time to degrade contaminants, and errors in assessing plume movement (retardation and groundwater speed) increase as distance from the source increases. For the ‘local’ problem considered here, the important parameters that drive the analysis are the DML rate assigned to each work block and the groundwater flow direction. Based on the flow model calibration results presented in subsection 5.3.1.1, we assume here that the parameters affecting the groundwater flow direction are ‘known,’ and therefore, the calibration analysis relies on adjusting the work block DML rate to match the data.

A third point to make here has to do with the water quality data associated with pumping wells. Because pumping wells pull in water from a large volume of aquifer, the resulting water quality data is in fact a measure of the average aquifer conditions associated with that volume. In this case, the CTM has a finer resolution than is afforded by the pumping well data. Therefore, one expects a strong correlation between measured and predicted values.

There are five COCs that constitute most of the mass in the South plume, namely 1,2,4-trichlorobenzene, 1,2 -dichlorobenzene, chlorobenzene, tetrachloroethene (PCE), and trichloroethene (TCE). Of these five, we have chosen three representative compounds for discussion here: chlorobenzene (CB), 1,2,4-trichlorobenzene (1,2,4-TCB) and tetrachloroethene (PCE), based on the following criteria:

1. Distribution within the source areas and in the plume. CB is the most widely distributed compound and constitutes the most mass in both the sources and the plume. Both 1,2,4-TCB and PCE are more sporadically distributed in both the sources and the plume.
2. Aquifer Restoration Standards (ESD Table 2)– All three compounds have relatively low values (CB = 4 ppb, 1,2,4-TCB = 8 ppb, and PCE = 1 ppb)
3. Water solubility – CB is a relatively high solubility compound (500 ppm), and 1,2,4-TCB and PCE are relatively low solubility compounds (19 and 150 ppm, respectively).

Note that the criteria listed above are also used to target work blocks for remediation by identifying those compounds that have the greatest impact on groundwater quality. As will be discussed in Section 6.0, the three compounds chosen here are the typical drivers for source remediation.

Figures 5.20 through 5.22 provide a comparison of the observed and CTM-predicted cumulative mass extracted at each '85 purge well during their operation (1/85 through 10/95) for CB, 1,2,4-TCB and PCE, respectively. The plot of cumulative mass extracted versus time is of particular interest for the following reasons:

1. The slope of the curve provides a measure of the magnitude of the dissolved mass loading rate (DML rate) from source areas. For example, high DML rates are associated with steep slopes, and low DML rates are associated with mild slopes.
2. The change in slope of the curve provides a measure of the trend in the DML rate. For example, a uniform trend in the DML rate (i.e., a constant slope) implies a regularity associated with the processes causing dissolved mass loading. On the other hand, an abrupt change in trend implies that one or more important processes are only intermittently active. Trend behavior provides important information regarding how the sources will behave into the future.

From this discussion, following observations are made based upon review of Figures 5.20 through 5.22:

1. The calibration results for CB, the most widely distributed compound, show a general over-prediction at each purge well. 1,2,4-TCB and PCE are by contrast more sporadically distributed in the sources and in the plume, and their results tend to show either a good match or a general under-prediction. There is a correlation between contaminant distribution within the source area and the DML rate prediction. Recall that the source model requires that each work block be represented by a uniform mixture of contaminants (see Table 5.2). Work block number and size are in part defined based on satisfying this requirement. However, due to the high variability of mass distribution, the uniformity requirement is only approximately satisfied. The result is that by trying to apply one partitioning efficiency to each work block, to capture the 'best' response of all COCs, the DML rate for the COC with the most uniform distribution (CB in this case) tends to be over-predicted.
2. The slope of each curve is an indication of the DML rate from source areas. Steep slopes indicate a high rate, and mild slopes indicate a low rate. The modeled slope describing CB is consistently higher than observed, indicating that a uniform reduction in the DML rate would result in a better correlation to data. On the other hand, the modeled slope for 1,2,4-TCB is in general well defined. In trying to match 1,2,4-TCB data, the work block DML rate had to be increased relative to that required for CB, thereby forcing CB's DML rate to be higher. This particular parameter set was chosen because we consider an over-prediction in the DML rate to be a conservative estimate when it comes to assessing work block remediation. That is, because higher DML rates result in higher groundwater concentrations, more source remediation is required to obtain the same restoration standard.
3. The PCE data show a time trend that is different from both CB and 1,2,4-TCB. Specifically, the observed data show that, in general, the DML rate was much higher from 1985 to 1990 (relatively steep slope) than is was from 1990 to 1995 (relatively mild slope). The CTM did not capture the dynamic first part of the curve. However, after 1990, the slopes of the two data sets are similar. This indicates that the source for PCE was initially much more dynamic than the CTM predicted (and more dynamic than the other compounds shown), but the dynamic nature was short lived, and for the last five years of data the CTM predictions show a similar trend.
4. For both CB and 1,2,4-TCB the ten years of data show a fairly-uniform trend in the DML rate from source areas (i.e., the data show a fairly-straight line). For PCE, the last five years of data show the same uniformity. When compared to the overall trends in the data, the CTM also shows the same uniformity. This behavior indicates that the physical processes that cause contamination to migrate from source areas to the aquifer are in general systematic, and they are approximated by the CTM. This uniformity supports the assessment that the CTM can be used to predict future mass loading trends.
5. Both the model and the data are in agreement with respect to the fact that the major portion of the South plume is located along the eastern edge of the source areas. This feature verifies both the flow model predictions and the dissolved mass entry points chosen.

From these observations, the following conclusions are drawn regarding the validity of the source model as a predictive tool the define the DML rate for the South plume:

1. The fact that the CTM can predict an accurate, uniform, trend in the DML rate for multiple compounds verifies that the source model incorporates the correct physical processes that govern source mass dissolution.
2. The CTM provides a conservative estimate of the trend in DML rate for Chlorobenzene, and an appropriate trend for both 1,2,4-TCB and PCE.
3. The uniformity of the observed DML trend supports the assessment that the CTM can be used to predict future mass loading trends.

5.3.2.3.2 Summary

The following bullets represent a summary of the major points contained in this section on South plume calibration:

1. Both the groundwater flow patterns (Figures 5.17 and 5.18) and the groundwater quality data (Figures 5.19) support the conclusion that from 1985 to present a ‘local’ capture system has been in place. This condition has resulted in plume attenuation down-gradient of capture wells.
2. The current groundwater flow patterns under the influence of the GERS (Figure 5.18) show that contaminant mass loading from the DDA and FCD work blocks is being contained by a subset of pumping wells in close proximity to the sources.
3. In general, the source model predicts both time-trend and magnitude of contaminant mass loading rate to the aquifer (Figures 5.19 through 5.22). This condition supports the conclusion that the CTM has utility in predicting future mass loading to the aquifer, and in so doing, allows it to be used as an aid to assess remediation alternatives.

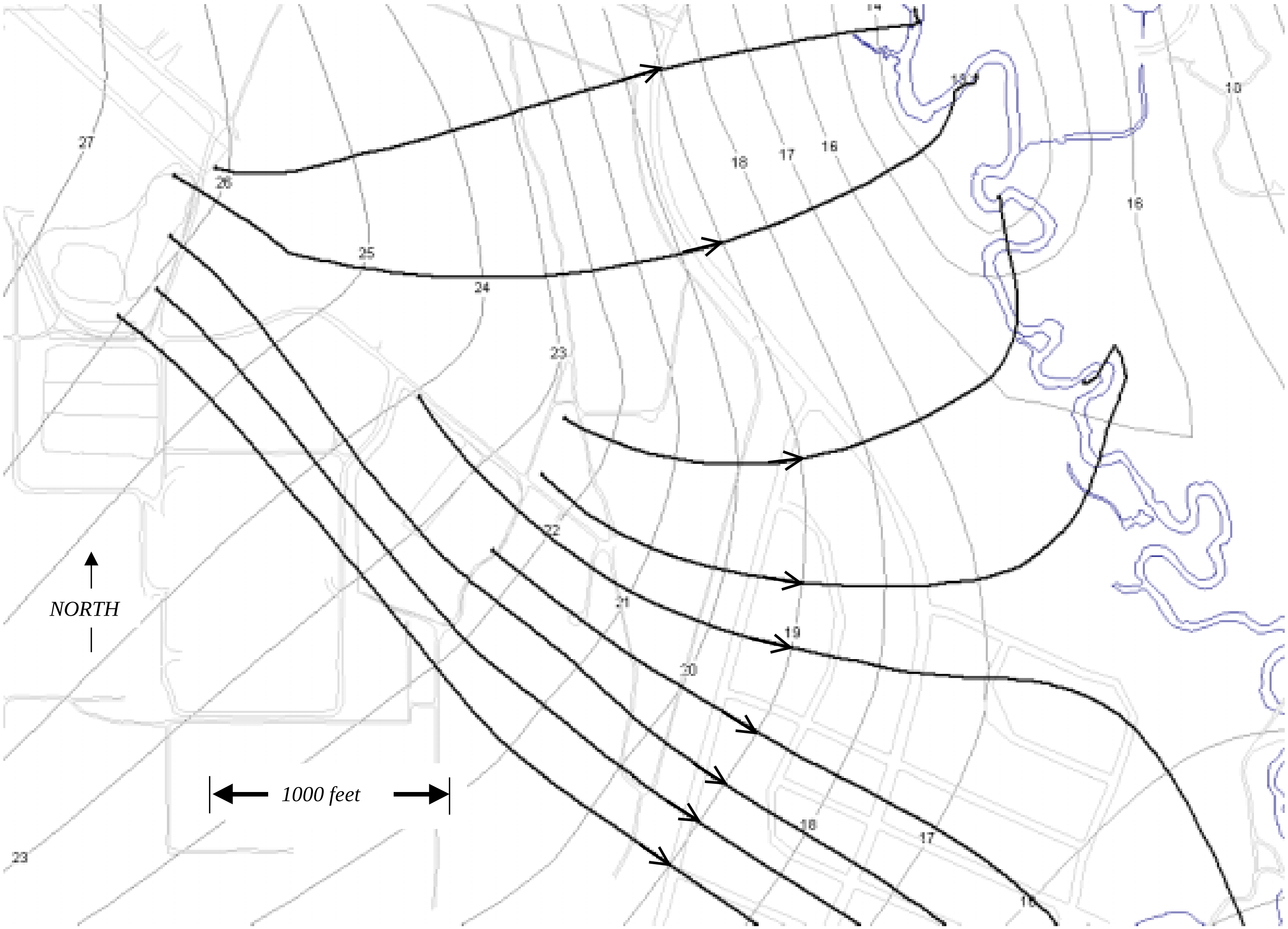

Figure 5.17 – CTM-generated groundwater flow field in the Primary Cohansey prior to 1985 (i.e., before pumping wells were installed in the southern portion of the site). The numbered contours represent groundwater head (1 foot contour interval). The heavy lines with arrows represent the groundwater flow paths under average rainfall and river stage conditions. The arrow indicates direction of flow. The results show that groundwater flows to the south and east toward the Toms River.

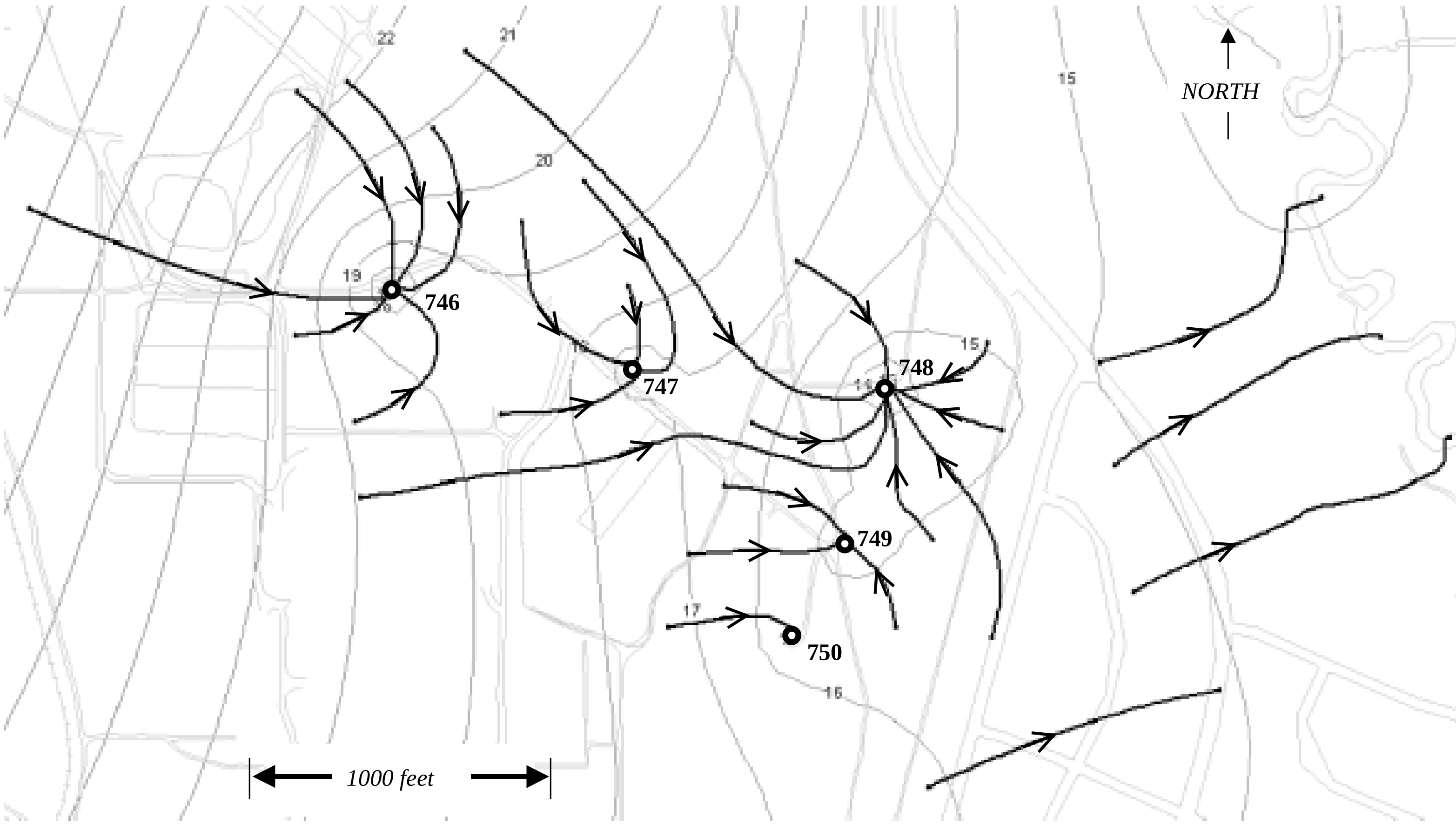

Figure 5.18 – CTM-predicted groundwater flow direction in the Primary Cohansey during the operation of the purge wells 1/85 through 10/95 (identified by open circles and bold numbers). The numbered contours represent groundwater head (1 foot contour interval). The heavy lines with arrows represent the groundwater flow path under average pumping conditions. The arrow indicates direction of flow.

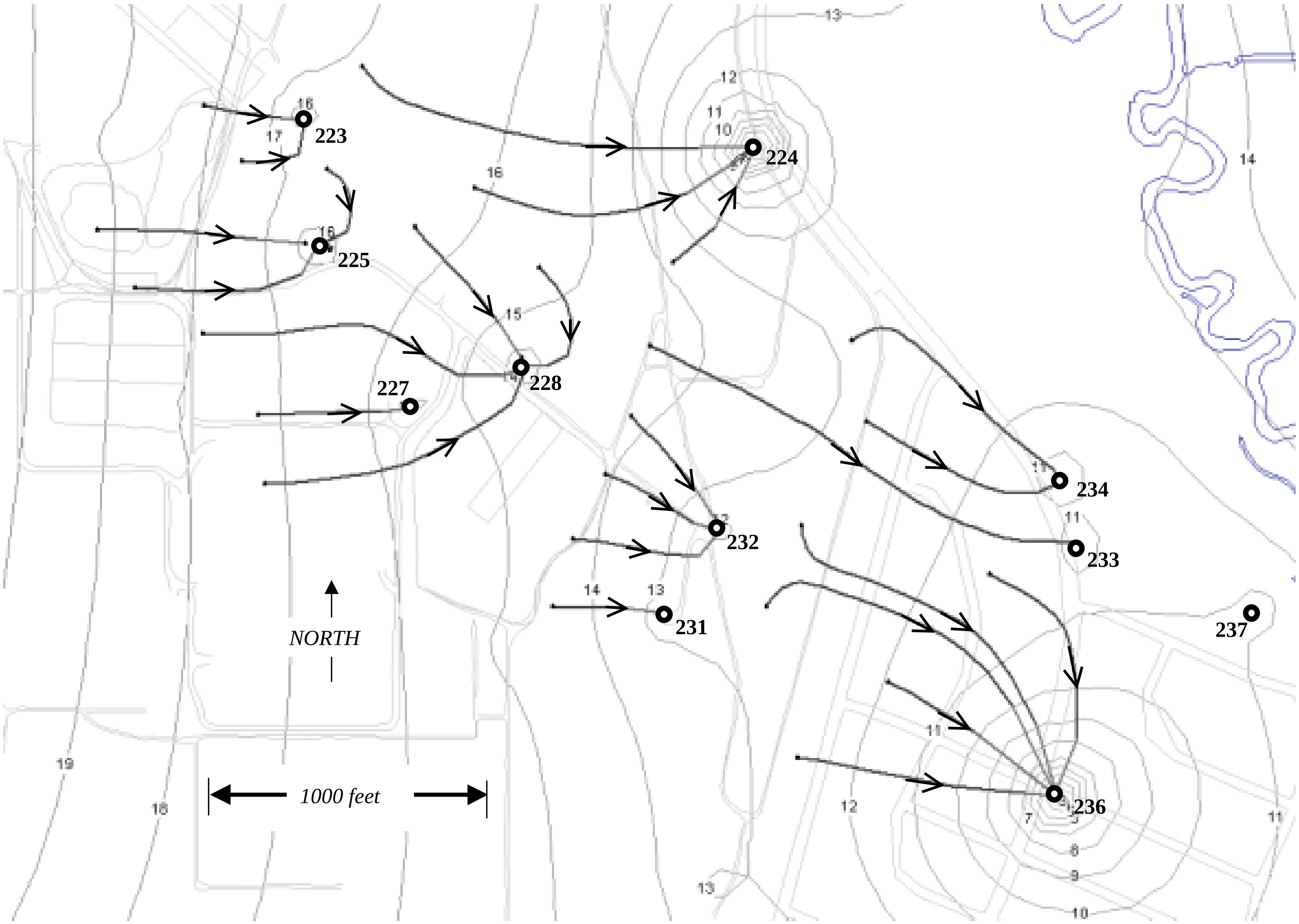

Figure 5.19 – CTM-predicted groundwater flow direction in the Primary Cohansey during the operation of the GERS wells 10/95 through present (identified by open circles and bold numbers). The numbered contours represent groundwater head (1 foot contour interval). The heavy lines with arrows represent the groundwater flow path under average pumping conditions. The arrow indicates direction of flow.

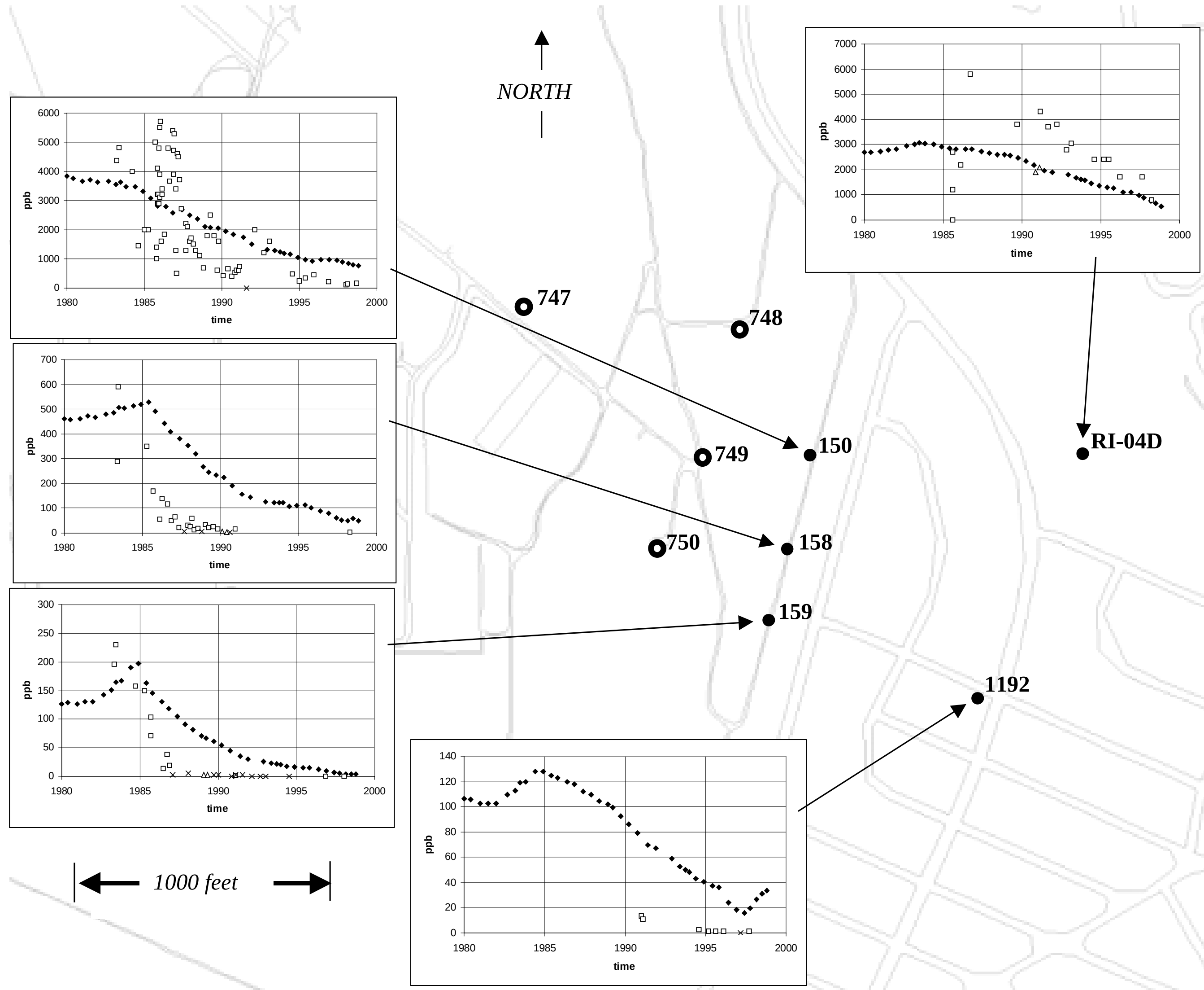

Figure 5.20a – Chlorobenzene behavior at monitor locations in the Primary Cohansey and down-gradient of the capture zone created by the ’85 purge wells (open circles on the map). The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected.

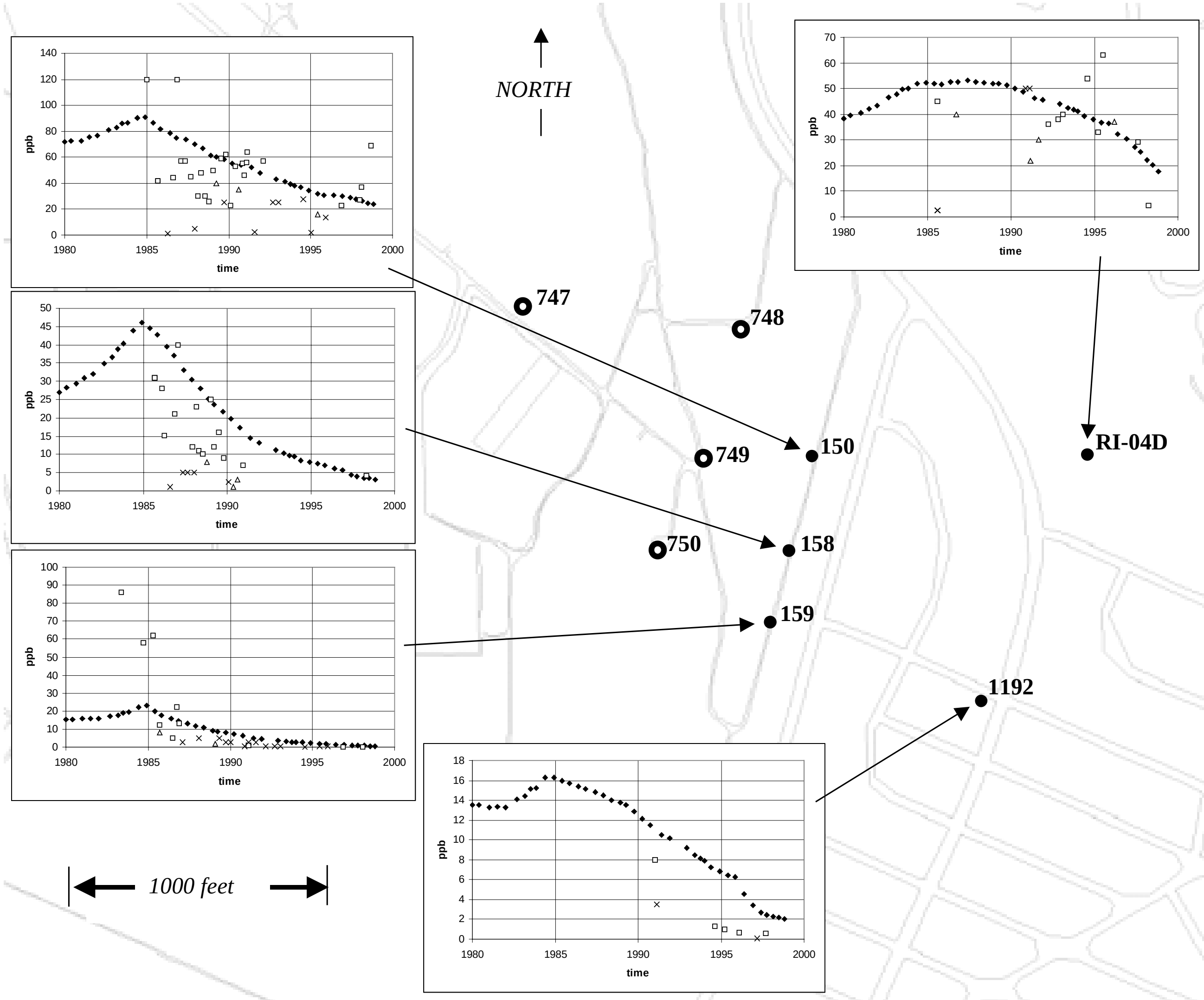

Figure 5.20b – Trichloroethene behavior at monitor locations in the Primary Cohansey and down-gradient of the capture zone created by the '85 purge wells (open circles on the map). The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected.

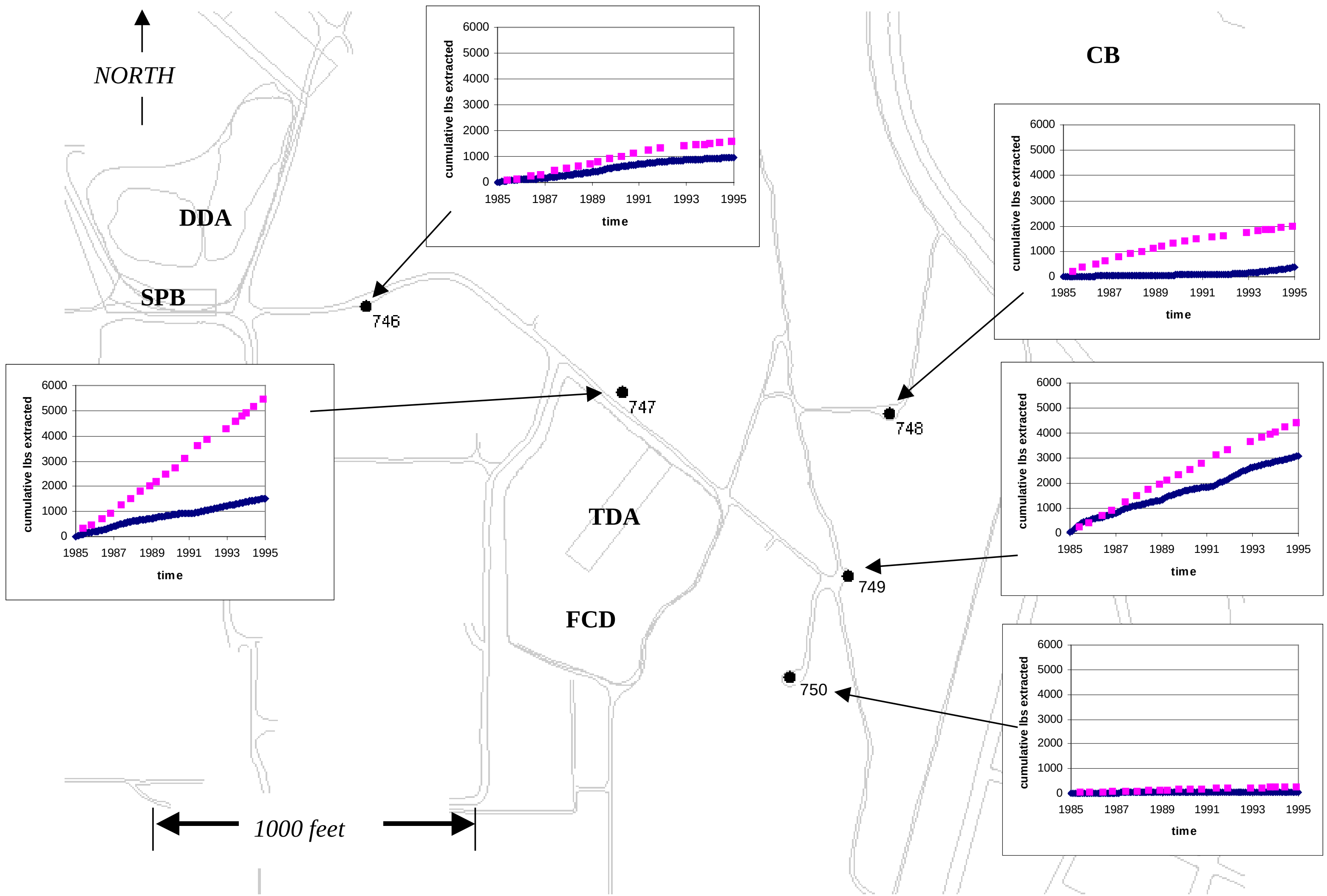

Figure 5.21a – Chlorobenzene (CB) mass extracted at each of the five purge wells, 1/85 through 10/95. For each purge well (numbered black dots on map) the corresponding plot shows the cumulative pounds of CB extracted with respect to time, where the black line represents the observed data and the gray squares represent the CTM result.

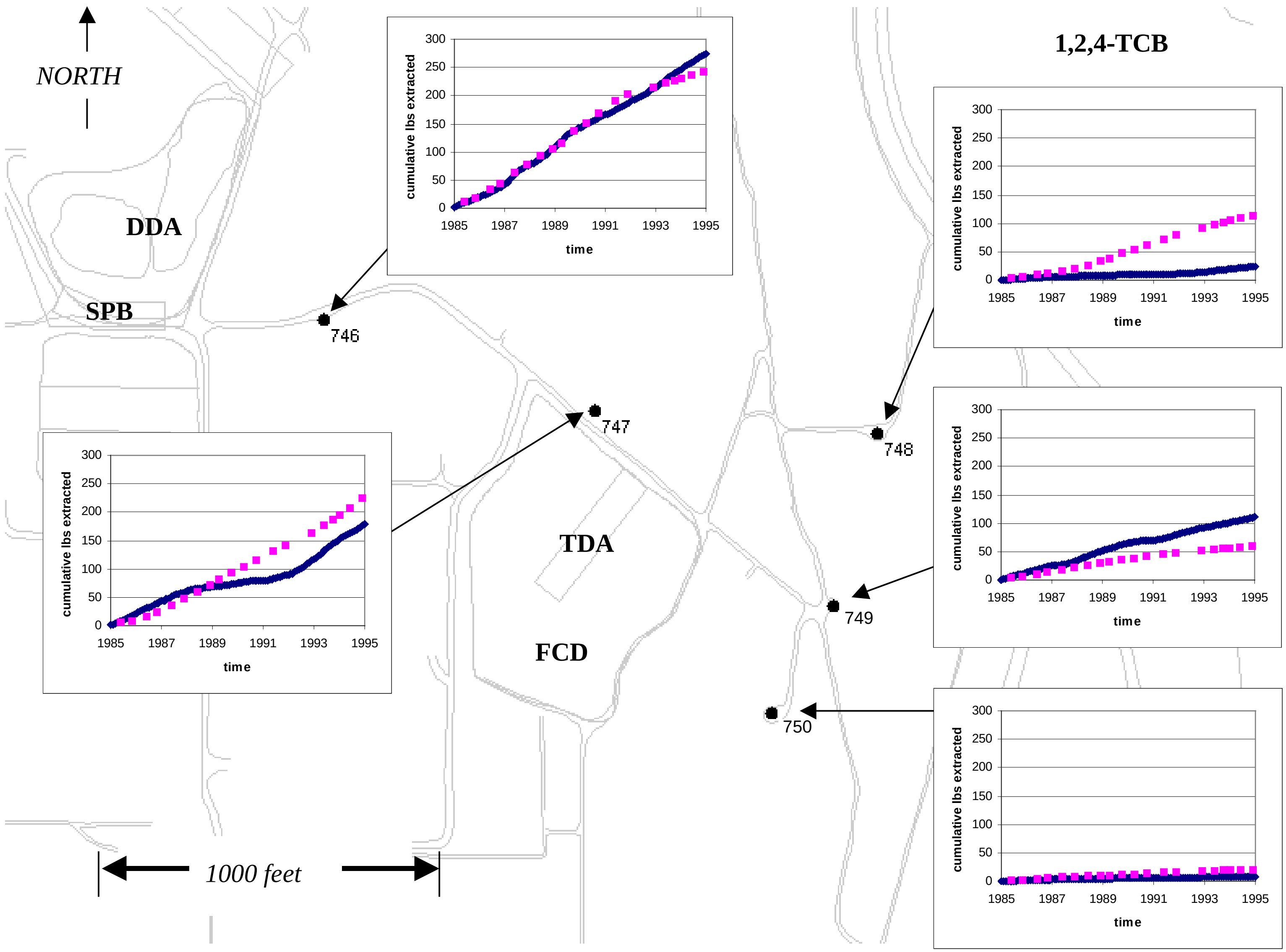

Figure 5.21b – 1,2,4-Trichlorobenzene (1,2,4-TCB) mass extracted at each of the five purge wells, 1/85 through 10/95. For each purge well (numbered black dots on map) the corresponding plot shows the cumulative pounds of 1,2,4-TCB extracted with respect to time, where the black line represents the observed data and the gray squares represent the CTM result.

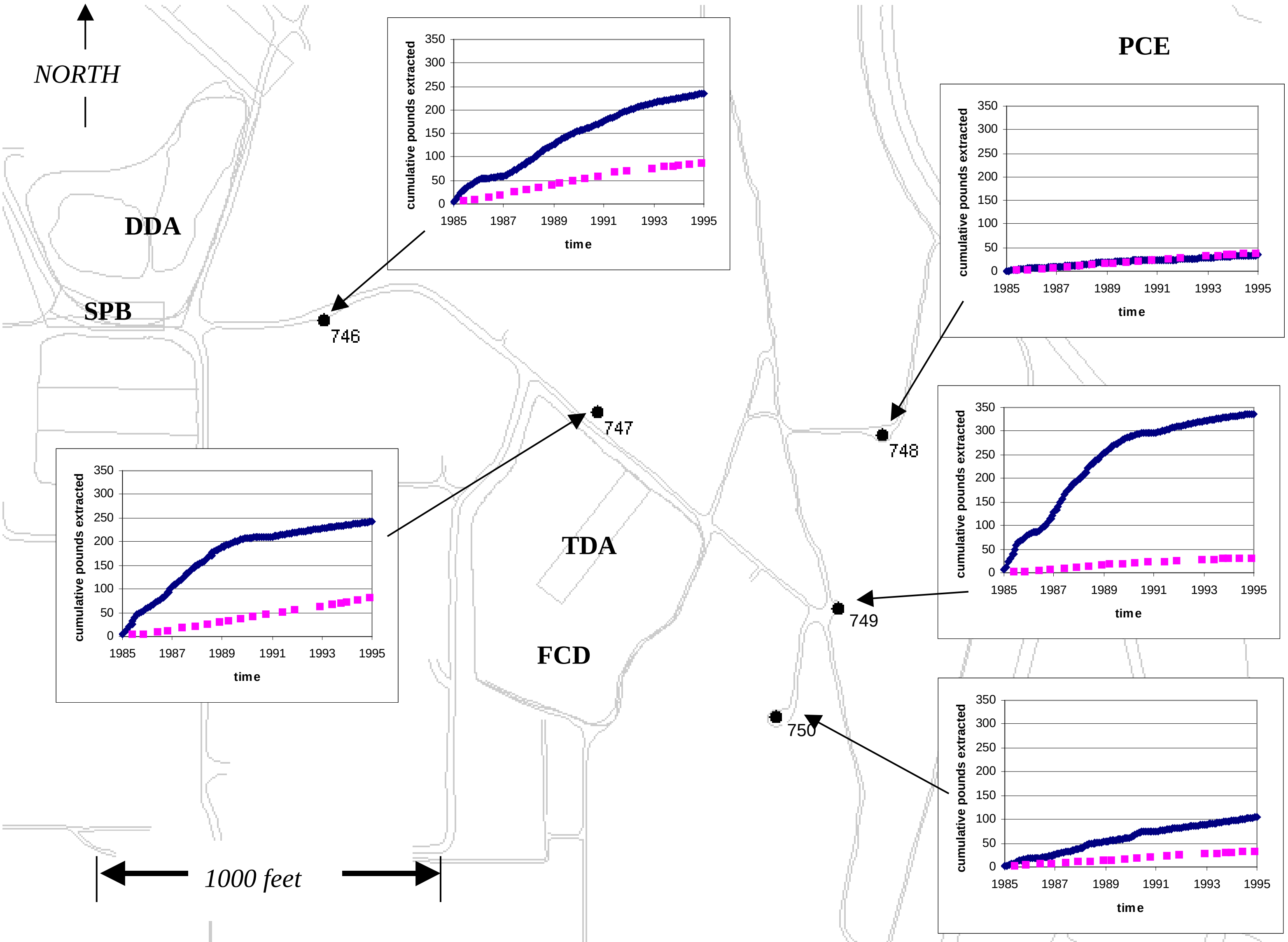

Figure 5.22 – Tetrachlorethene (PCE) mass extracted at each of the five purge wells, 1/85 through 10/95. For each purge well (numbered black dots on map) the corresponding plot shows the cumulative pounds of PCE extracted with respect to time, where the black line represents the observed data and the gray squares represent the CTM result.

5.3.2.3.3 North Plume Calibration

As with the development for the South plume, before presenting and discussing the results of the calibration effort for the North plume, let us first discuss some of the important local attributes that have a significant effect on the distribution of contaminants in this part of the aquifer. These attributes include source location, geology (i.e., the layering of soils) and hydrology (i.e., the groundwater flow patterns). In addition, we will discuss a unique source for contaminant mass in the North plume, namely mass that entered the aquifer as a dissolved phase in plant process water, and its effect on calibration.

With respect to the location of the sources contributing to North plume contaminant mass, as discussed in Section 3.3, there are four major source areas, namely:

- The Equalization Basins, the West Basin (WEQ) and the East Basin (EEQ),
- The Former South Dye Area (FSD),
- The former Building 108/Underground Storage Tank Area (B108), and
- The Borrow Compactor Area (BCA).

Figure 5.23 provides a location map for these source areas.

Also in Figure 23, an important geologic feature is illustrated, that is, the distribution of the Yellow Clay unit. Note that only the FSD area is located above this intervening unit. See Figure 5.11 for a schematic of the effect that the clay layer has on work block dissolved mass loading location. The clay not only redirects dissolved mass to its edge before entering the Primary Cohansey, but because of the presence of sand stringers (or lenses) within the clay, there are local entry points that “short circuit” the general trend.

As discussed previously, the dissolved mass entry points to the Primary Cohansey are determined from an assessment of geology-, hydrology-, and water quality-related data. The data used to assess north plume dissolved mass entry points is summarized in Table 5.8. The resulting dissolved mass entry points for the north plume source areas are shown in Figure 5.29.

Table 5.8 – Summary of the data used to assess the dissolved mass loading entry points to the Primary Cohansey from north plume source areas.

data	information support	time-related data	spatial coverage
soil borings	▪ stratigraphy of the Upper Cohansey and Yellow Clay ▪ contamination in the soil	one-time data point	Figure 5.24
monitor wells screened in the perched water system	▪ stratigraphy of the Upper Cohansey and Yellow Clay ▪ water quality of the perched system.	intermittent sampling for organic compounds 1985 through present.	Figure 5.25
monitor wells screened in the Primary Cohansey	▪ stratigraphy of the Upper Cohansey, Yellow Clay and Primary Cohansey. ▪ water quality of the Primary Cohansey.	intermittent sampling for organic compounds 1985 through present.	Figure 5.26
monitor wells screened in the Lower Cohansey	▪ stratigraphy of the Upper Cohansey, Yellow Clay, Primary and Lower Cohansey, and Cohansey-Kirkwood Transition Member. ▪ water quality of the Lower Cohansey.	intermittent sampling for organic compounds 1985 through present.	Figure 5.27
Groundwater profiles - Direct Push Technology (DPT) points	▪ stratigraphy of the Upper Cohansey, Yellow Clay, Primary and Lower Cohansey, and Cohansey-Kirkwood Transition Member. ▪ water quality of the perched system and the Primary and Lower Cohansey.	one-time data point	Figure 5.28

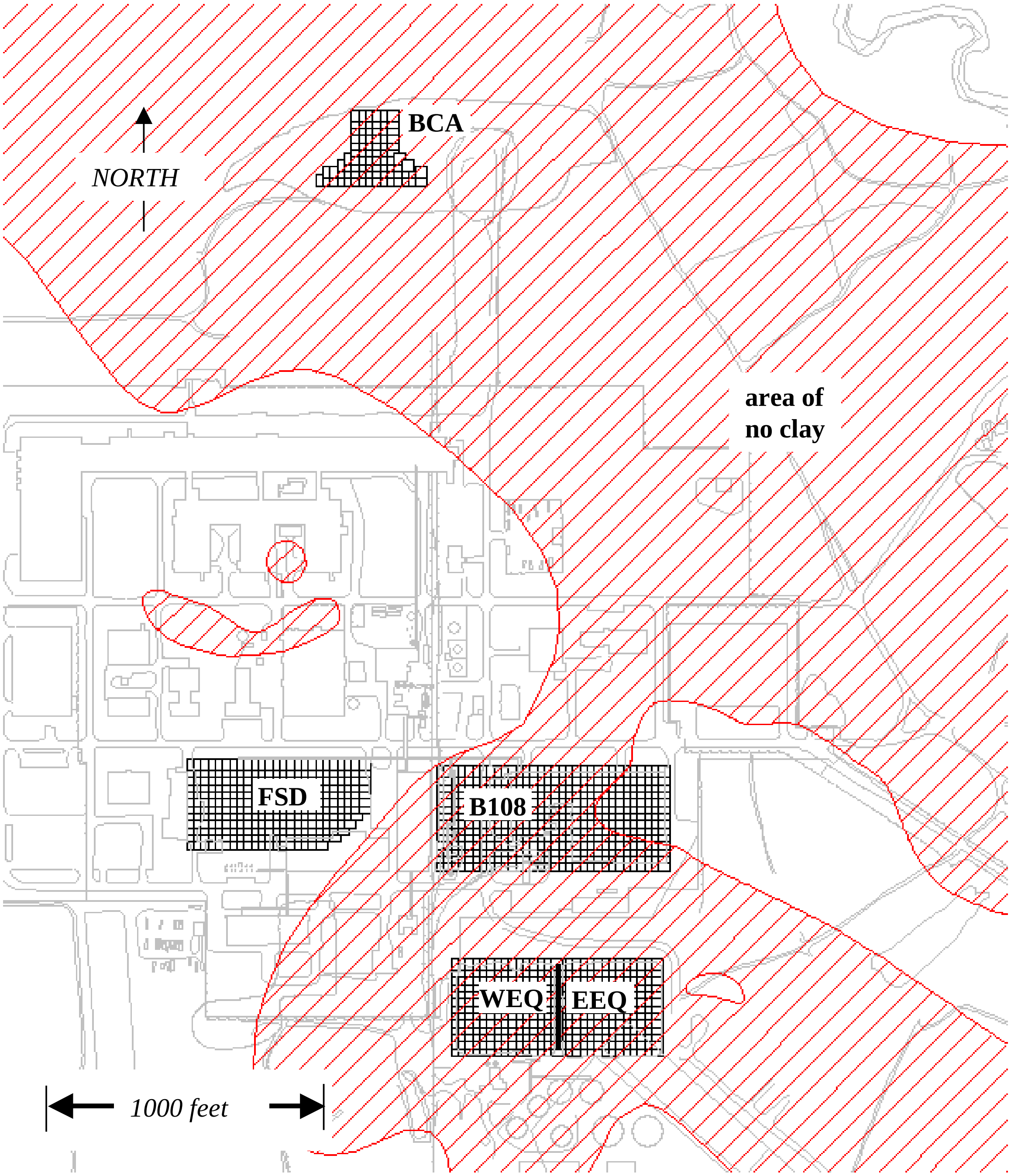

Figure 5.23 – Location map of north plume source areas. The source areas are delineated by the plan-view of their respective work blocks. The lined overlay areas indicate areas where the Yellow Clay unit is not present. Note that only the FSD has an intervening clay unit between it and the Primary Cohansey (i.e., see Figure 5.11).

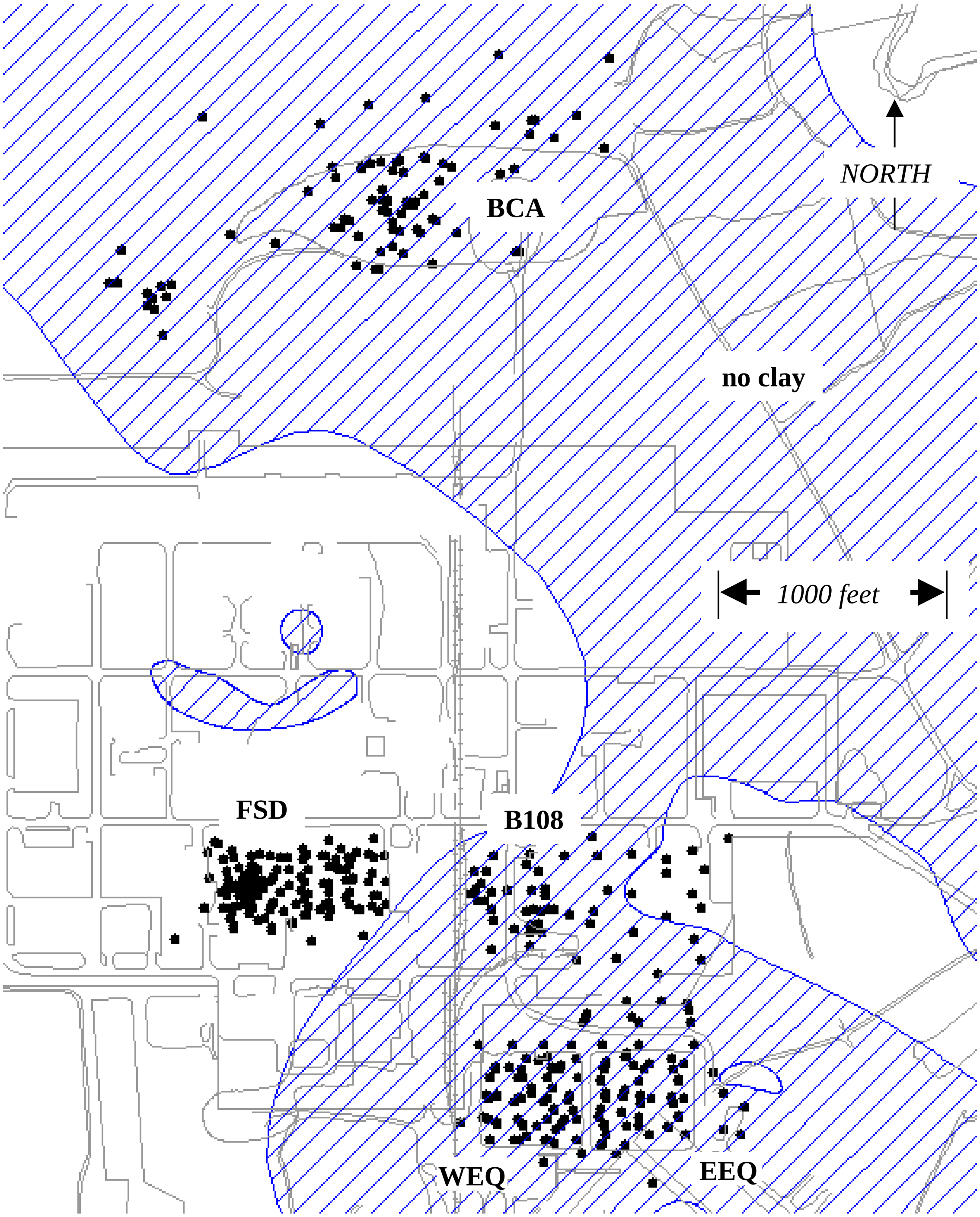

Figure 5.24 – Location map of the soil borings providing characterization data for the extent of the source areas and the extent and continuity of the Yellow Clay (black dots). This data is used in part to determine the dissolved mass entry points to the Primary Cohansey.

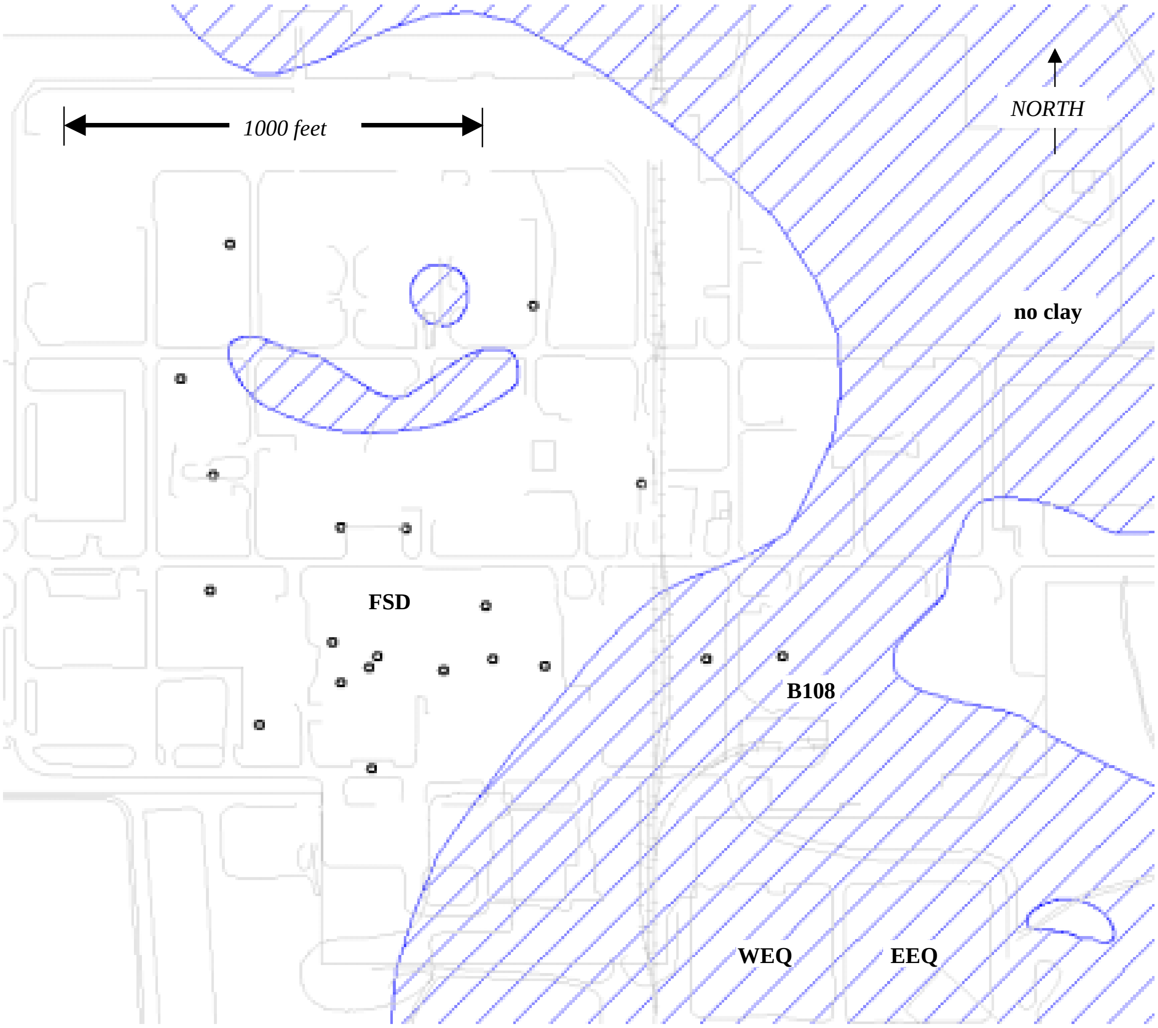

Figure 5.25 – Location map of the monitor wells screened in the perched water system (black circles) in the north plume area. The data from these wells provides characterization data for the extent and continuity of the Yellow Clay (boring logs), and perched water quality. The cross-hatched areas indicate areas where the Yellow Clay is not present. This data is used in part to determine the dissolved mass entry points from source areas to the Primary Cohansey.

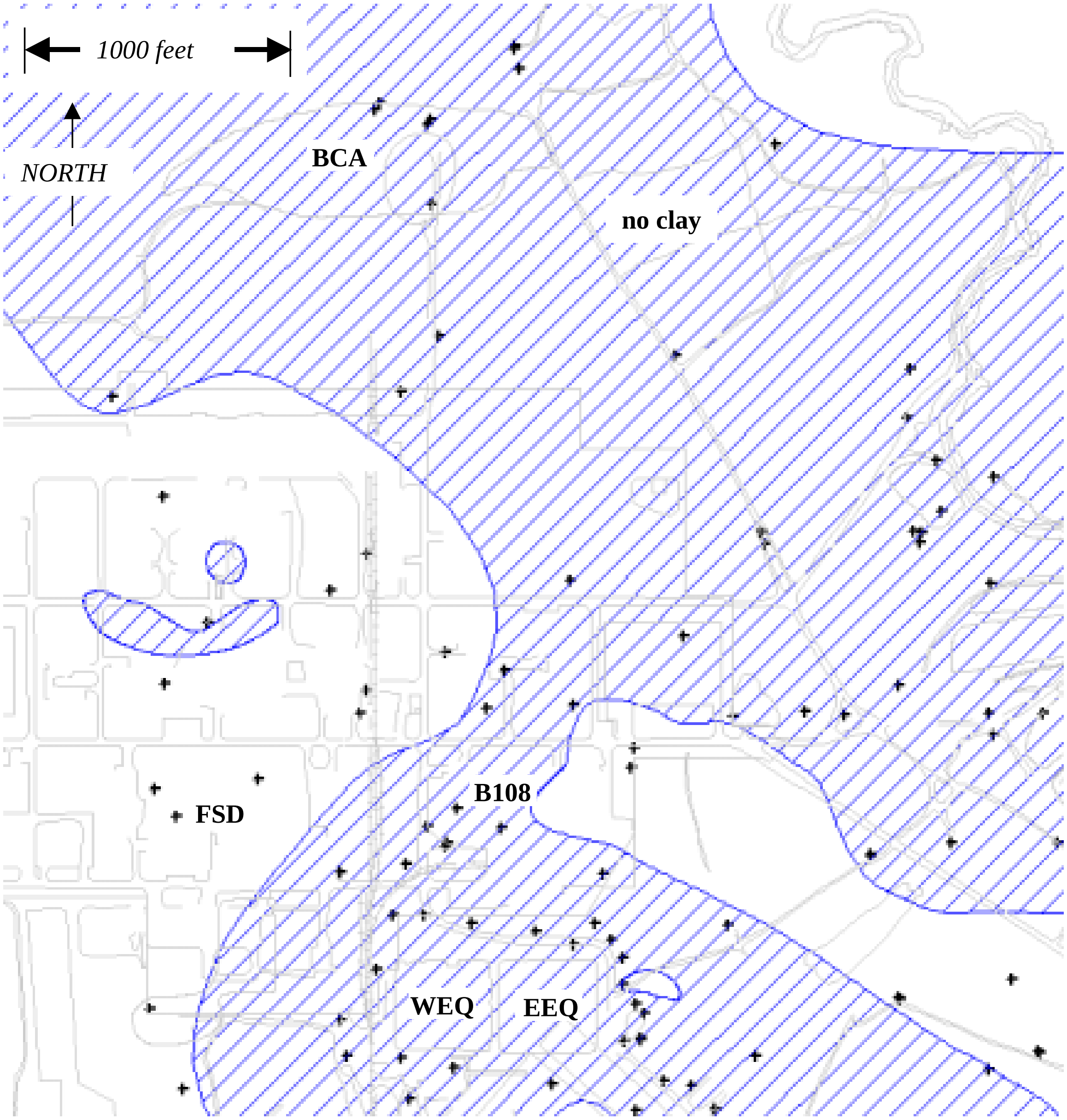

Figure 5.26 – Location map of the monitor wells screened in the Primary Cohansey (black crosses) in the north plume area. The data from these wells provides characterization data for the extent and continuity of the Yellow Clay (boring logs), and aquifer water quality. The cross-hatched areas indicate areas where the Yellow Clay is not present. This data is used in part to determine the dissolved mass entry points from source areas to the Primary Cohansey.

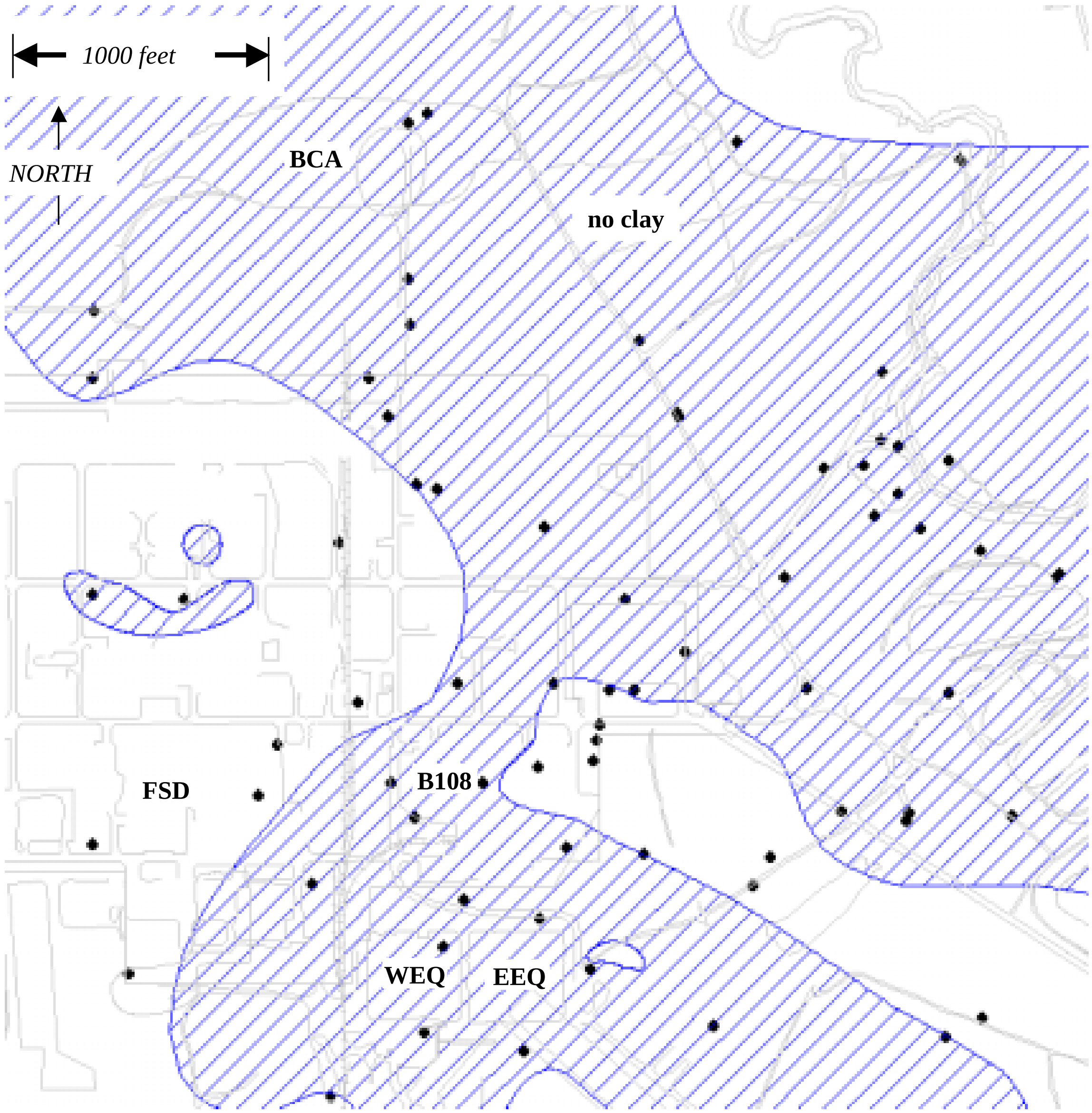

Figure 5.27 – Location map of the monitor wells screened in the Lower Cohansey (black diamonds) in the north plume area. The data from these wells provides characterization data for the extent and continuity of the Yellow Clay and the location of the Cohansey Kirkwood Transition Member (boring logs), and aquifer water quality. The cross-hatched areas indicate areas where the Yellow Clay is not present. This data is used in part to determine the dissolved mass entry points from source areas to the Primary Cohansey.

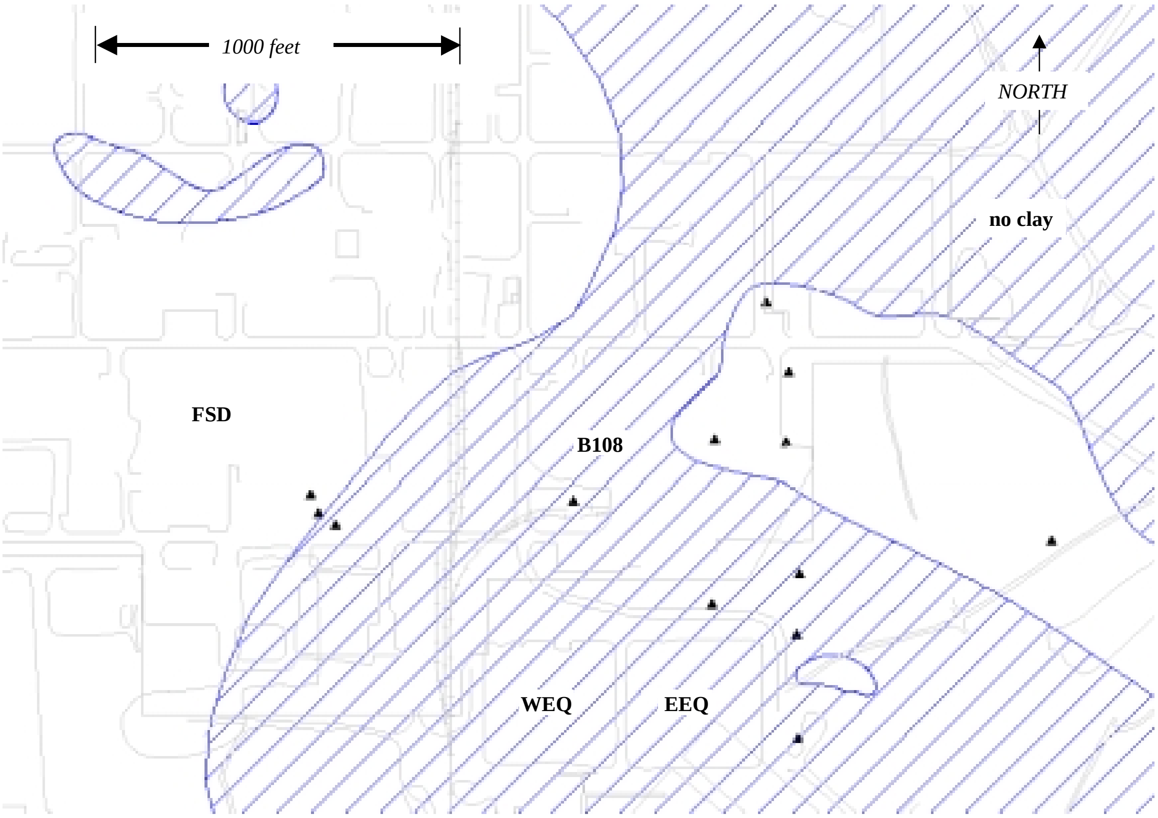

Figure 5.28 – Location map of the groundwater profile Direct Push Technology (DPT) data points (black triangles) in the north plume area. In general, these data points provide a vertical profile of geologic and water quality conditions through the Upper and Primary Cohansey. This data is used in part to determine the dissolved mass entry points from source areas to the Primary Cohansey.

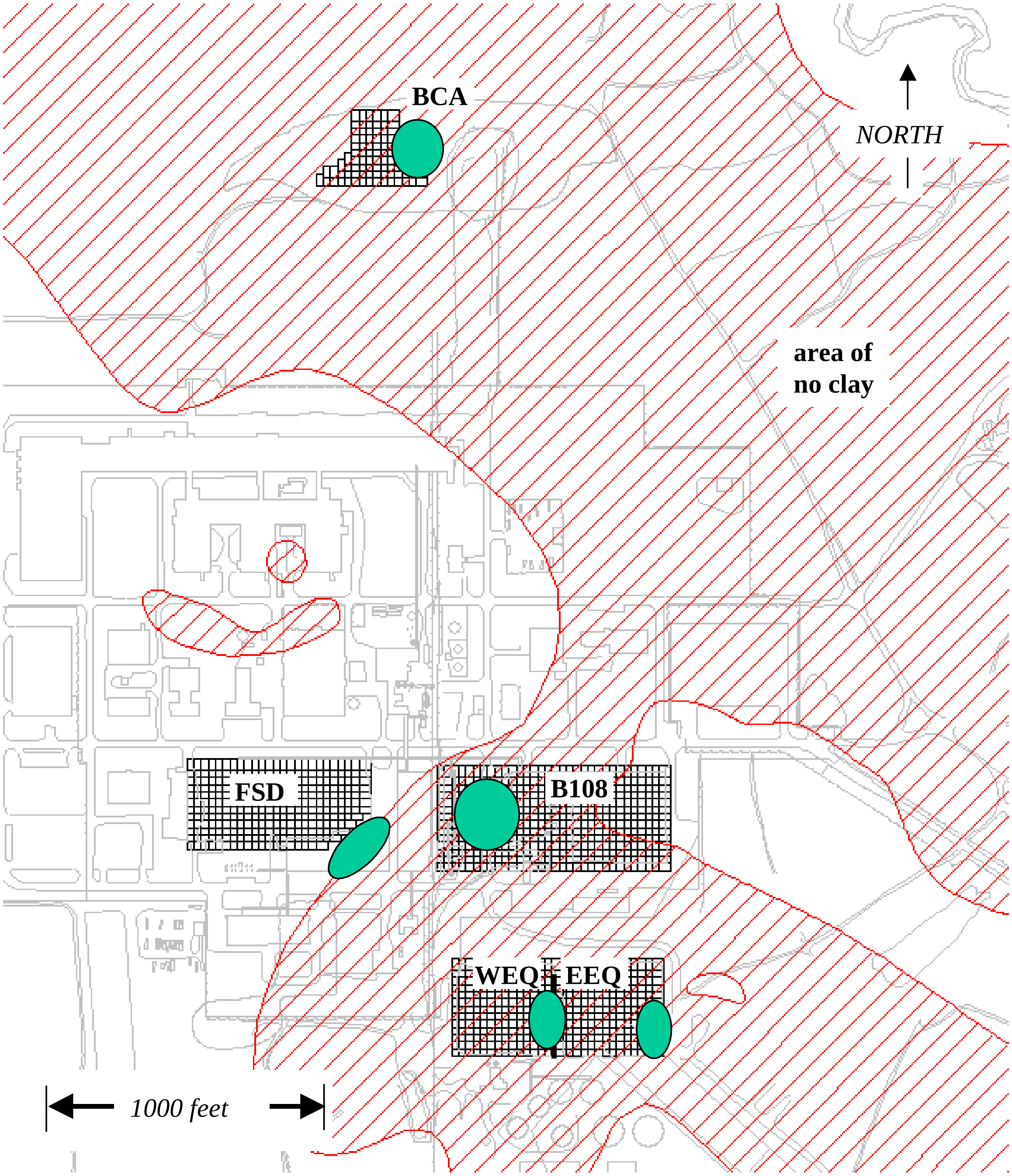

Figure 5.29 – Map view of the North plume source areas showing the approximate location of where the contaminant mass, leached from the source model work blocks, enters the top of the Primary Cohansey. One loading location (gray oval near respective work block) is assigned to each major source area, WEQ, EEQ, FSD, B108, and BCA. The source spill locations were determined based on local groundwater flow, water quality and geology (as per the data summarized in Table 5.8).

An assessment of the historical trends in the groundwater flow patterns in the Primary and Lower Cohansey Members provides significant insight into the current distribution of contaminants in the North plume. There are four major flow patterns that have affected the plume since the source areas have been contributing dissolved contaminant mass to the aquifer (approximately 1953 through the present, see Section 2 for details on plant operational history). The unique flow patterns are the direct result of different pumping well configurations.

Consider the following description of the well configurations that existed in the North part of the site from the 1950s to the present. Note that only those pumping wells that had a significant impact on contamination movement are discussed below.

1. 1952 through 1960 – Operation of facility "production" wells (called "production" wells because these wells supplied water for plant production processes). The location of the production wells and the CTM-modeled flow patterns in the Primary Cohansey resulting from average pumping conditions are shown in Figure 5.30. The contours represent groundwater head[2] in the Primary Cohansey, and the flow paths (bold curves) start in the top of the Primary Cohansey in the vicinity of source areas. Note that the flow paths converge at the well locations. The flow patterns in the vicinity of the EQ basins, FSD and B108 sources indicate that after picking up contaminant mass, the groundwater flows generally north and east toward wells P206 and P403. In the vicinity of the BCA, flow is south toward well P800. Note that this configuration of wells was abandoned due to a degradation in water quality from the wells. Because the wells are screened in the Lower Cohansey, this implies that the wells were drawing contaminated water through the Cohansey/Kirkwood Transition zone.
2. 1960 through 1985 – Operation of facility "production" wells. The location of the production wells and the CTM-modeled flow patterns in the Primary Cohansey resulting from average pumping conditions are shown in Figure 5.31. The contours represent groundwater head in the Primary Cohansey, and the flow paths (bold curves) start in the top of the Primary Cohansey in the vicinity of source areas. Note that the flow paths converge at the well locations. The flow patterns in the vicinity of the EQ basins, FSD and B108 sources indicate that after picking up contaminant mass, the groundwater flows generally north and east toward wells P200A and P800. In the vicinity of the BCA, flow is south and east toward wells P800 and P1200. Because the wells noted are screened in the Lower Cohansey, this implies that they were drawing contaminated water through the Cohansey/Kirkwood Transition zone.
3. 1/85 through 10/95 – operation of two pumping wells (called here the '85 purge wells) for the specific purpose of capturing the dissolved mass loading from the EQ basins. The location of the purge wells and the CTM-modeled flow patterns in the Primary Cohansey resulting from average pumping conditions are shown in Figure 5.32. Note that the flow patterns show capture of the groundwater that comes in contact with the EQ basin source area contamination. Also note that the groundwater flow direction north of the EQ basins in generally to the east, reflecting natural flow conditions.

[2] The groundwater *head* is a measure of the water pressure in the aquifer, and it provides information on water movement, because water will flow from a point of high head to a point of low head.

4. 10/95 to present – operation of the Groundwater Extraction and Recharge System (GERS). This system was implemented as the Operable Unit 1 remedy, and its intent is to capture the contaminant plume at the Site. Figure 5.33 shows the location of some of the GERS wells associated with the North plume. Also, this figure shows the CTM-modeled flow patterns generated as the result of average pumping conditions. The groundwater head contours are for the Primary Cohansey. Note that the groundwater that comes in contact with the source areas identified is captured by at least one GERS well.

These figures clearly show that the contaminant plume that exists in the Primary and Lower Cohansey to the north and east of the Building 108 area (i.e., see Section 3.3.3) is the result of past production well pumping configurations.

From a CTM calibration perspective, the flow patterns shown in Figures 5.32 and 5.33 indicate the following:

1. The two wells down-gradient of the EQ basins (i.e., wells 754 and 755 from 1985 to 1995 and wells 215 and 216 from 1995 to present) have been capturing EQ basin mass loading for more than ten years. Therefore, water quality data from these wells can be used as an effective measure of the mass loading rate from this source area.
2. Unlike the EQ Basins, there are no “capture” wells immediately down-gradient of the FSD, B108 and BCA source areas. Therefore, calibration of the mass loading character of these source areas must be conducted using local monitor well data and the model-predicted loading behavior of like sources which have a more complete calibration database.

Before proceeding to the calibration results for the north plume, an important component of current north plume contaminant mass, from a calibration perspective, must first be introduced. Namely, the mass that entered the aquifer as a dissolved phase in plant process water. There were three sources for this dissolved mass:

1. Leaking through process wastewater sewer lines that carried wastewater from the FSD production area to the EQ basins. This source for contaminated water existed from the 1950s to the 1980s.
2. Leaking through the EQ basins. This source for contaminated water existed from the 1950s to 1991 when the basins were decommissioned.
3. Leaking through the areas designated as the Old Settling Basin and Oxidation Lagoon. This source for contaminated water existed from the 1950s to 1960s after which the basins were decommissioned.

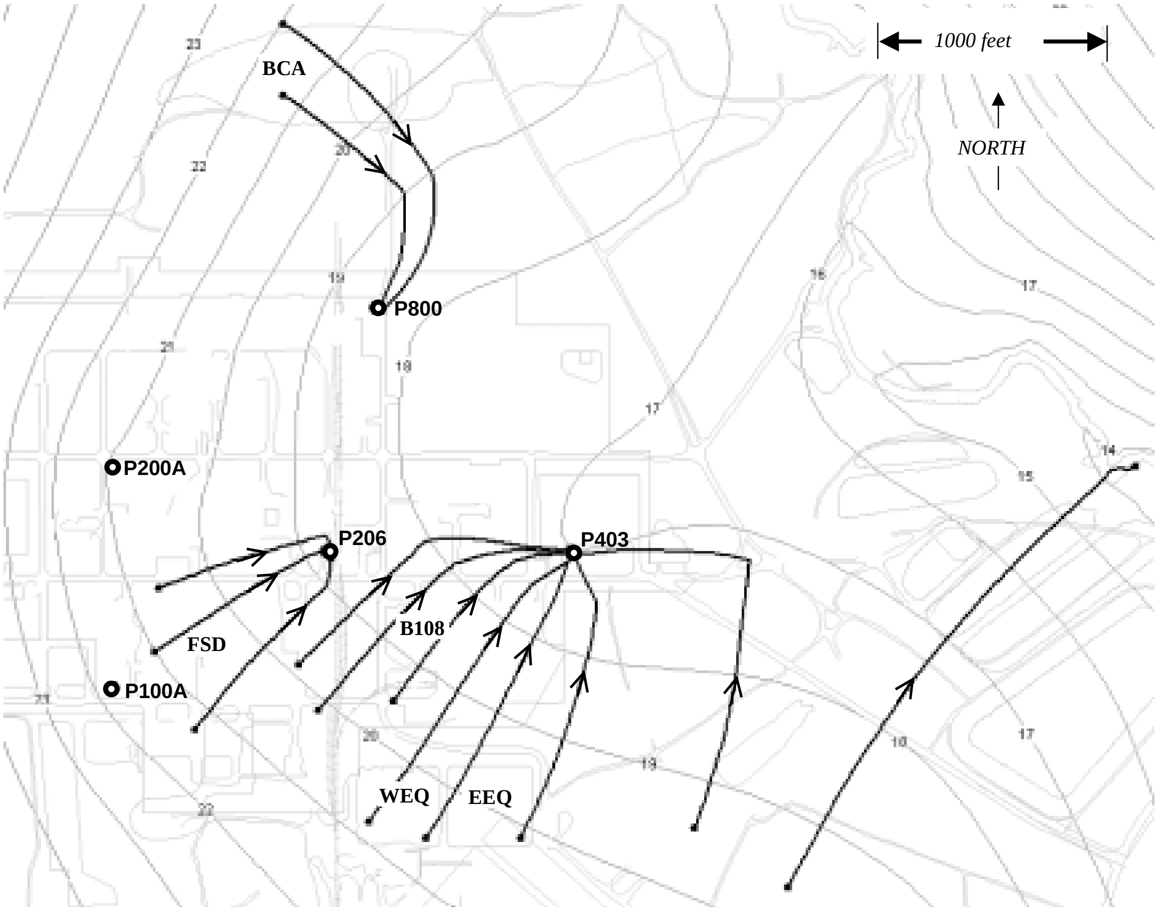

Figure 5.30 - Flow field 1953-1960. The contours represent the hydraulic head in the Primary Cohansey under average conditions over this period of time. Computed flow lines (bold lines with arrows) are started at the top of the Primary Cohansey. All the production wells (identified by open circles) are screened in the Lower Cohansey. Note, flow lines that end up in the Lower Cohansey are not perpendicular to Primary Cohansey head contours.

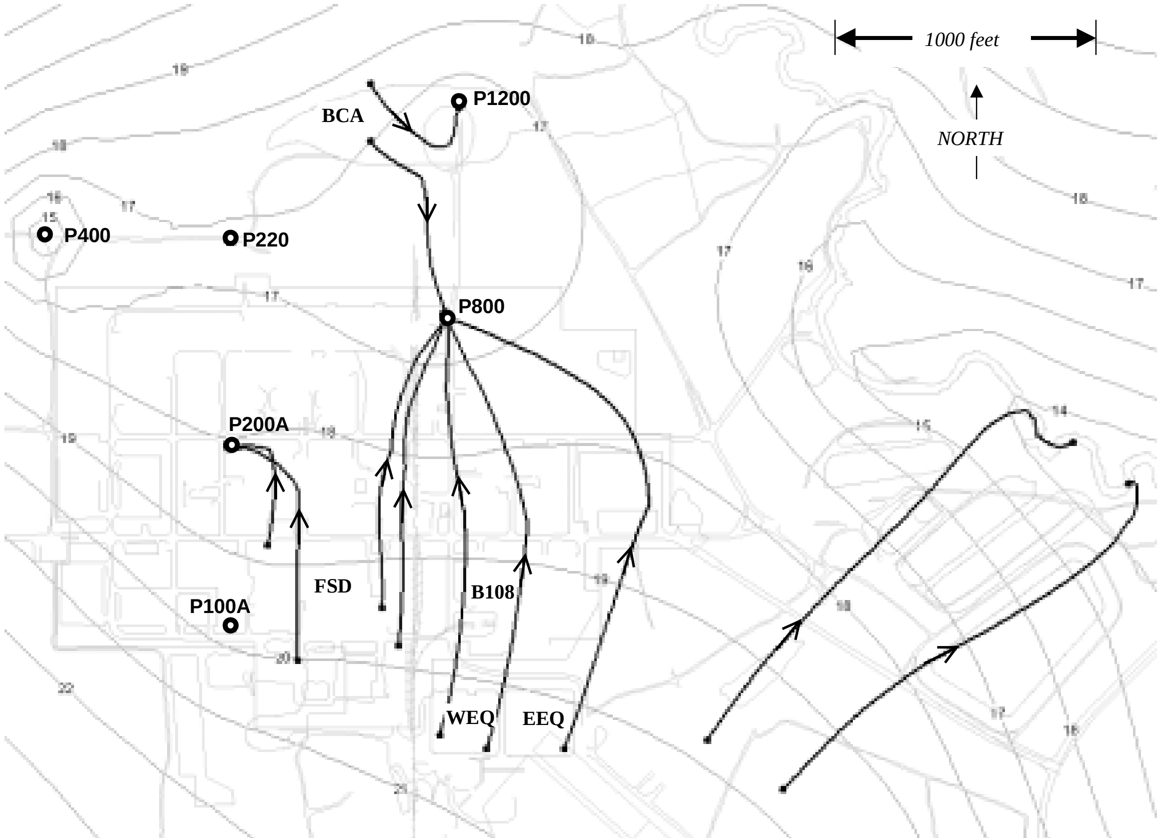

Figure 5.31 - Flow field 1960-1985. The contours represent the hydraulic head in the Primary Cohansey under average conditions over this time period. Computed flow lines (bold lines with arrows) are started at the top of the Primary Cohansey. All the production wells (identified by open circles) are screened in the Lower Cohansey. Note, flow lines that end up in the Lower Cohansey are not perpendicular to Primary Cohansey head contours.

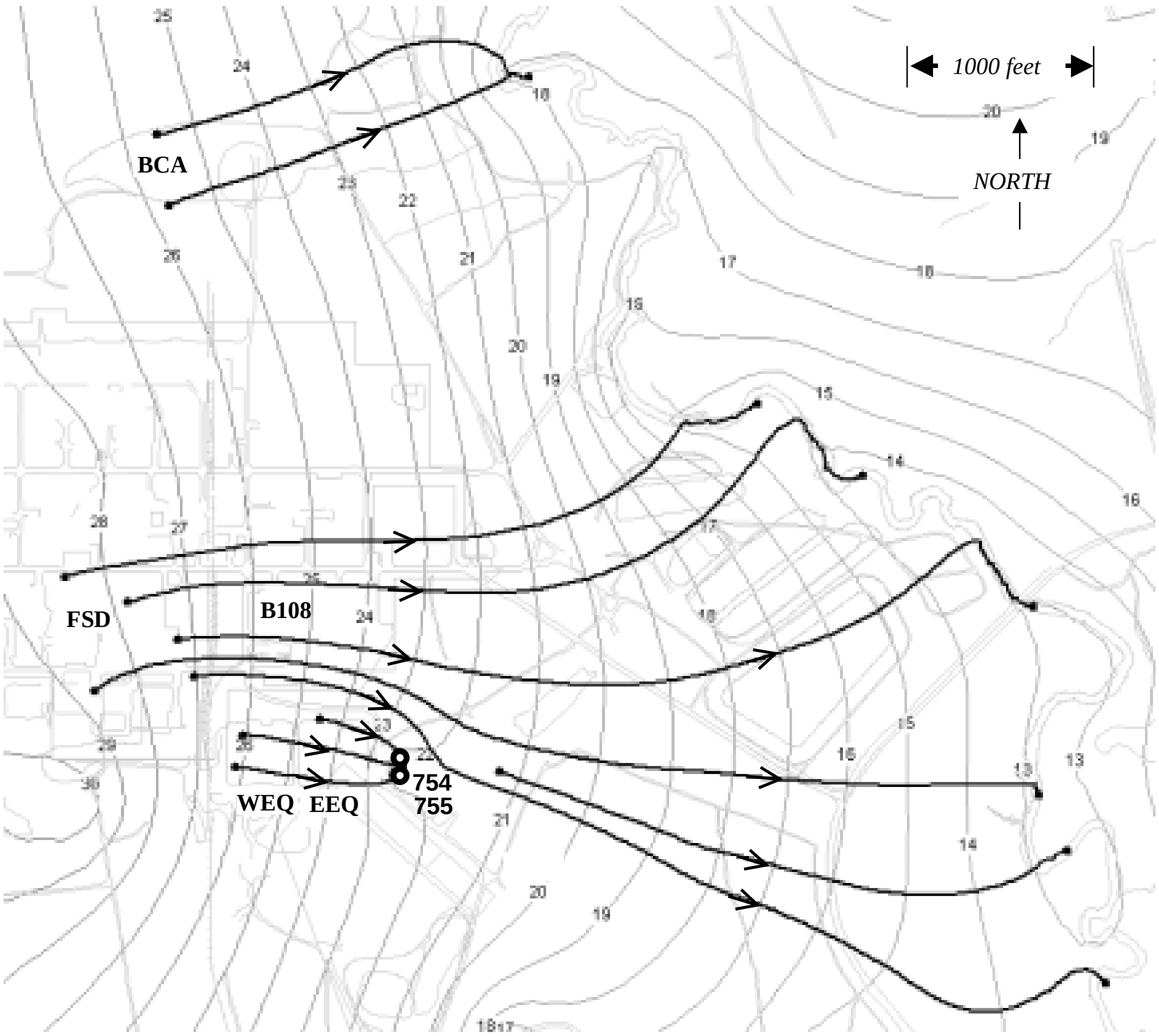

Figure 5.32 - Flow field 1985-1995. The contours represent the hydraulic head in the Primary Cohansey under average conditions over this time period. Computed flow lines (bold lines with arrows) are started at the top of the Primary Cohansey. The two purge wells shown are screened in the Primary Cohansey.

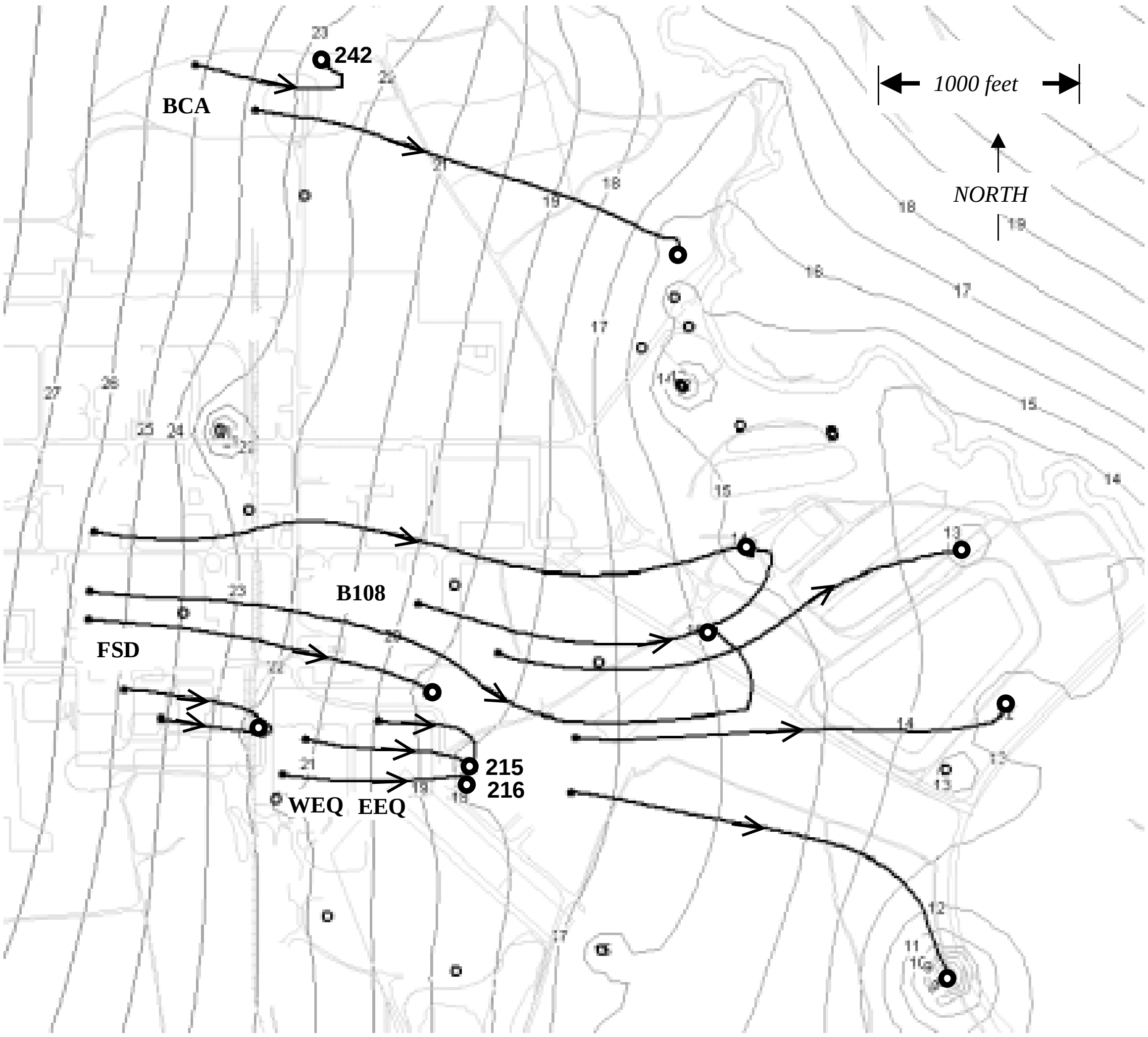

Figure 5.33 - Flow field 1995 to present under the influence of GERS pumping conditions. The contours represent the groundwater head in the Primary Cohansey under average conditions over this time period. Computed flow lines (bold lines with arrows) are started at the top of the Primary Cohansey. Open circles represent the location of a GERS pumping well.

There is an important distinction to be made between this source for dissolved contaminant mass in the aquifer, and that which results from the leaching of residual mass from source areas. Namely, the “leaking” processes listed above were sources for contamination only while the processes were active. That is, only while water was flowing through the system. When plant operations ceased (about 1991), the source for this dissolved mass loading stopped. This is unlike the current source areas which contain “residual” mass in the soil matrix that is continuing to leach mass into the aquifer as water flows through the source zone. It is these leaching sources that are the subject of the remediation efforts discussed in this FS.

Unfortunately, the dissolved mass loading rate from the “leaking” sources cannot be readily modeled using the CTM. This is because neither the chemical composition of the process water nor the flow rate can be determined with any certainty. This fact complicates the modeling associated with the current sources for contamination (i.e., the EQ basins, the FSD area, the B108 area, and the BCA), because the model cannot distinguish between aquifer mass that resulted from the two source types.

Therefore, to validate the model that describes the current mass loading rate from source areas, we must choose that part of the database that has a minimum impact from what effectively can be considered “background” concentration. Recall that the groundwater quality database spans a time-period from between about 1985 to the present. Because groundwater moves slowly (about one foot per day at the Site) and because plant process water stopped flowing around 1991, to obtain a measure of mass loading from source areas, we are forced to target wells that are in close proximity to each respective source. In addition to interrogating close proximity wells, we are also interested in data obtained at those wells after 1991. Based on this discussion, the time frame for north plume calibration ranges from 1992 to present. In order to model this time-frame, we have defined an initial groundwater plume dated at 1/1/92 for each of the nine COCs based on the available groundwater quality database (see Appendix C for details). This initial condition serves as a definition for the existing background contaminant mass in the system.

Calibration results are presented below for each of the four source areas considered: the Equalization Basins (EQ Basins) the Former South Dye Area (FSD), the Former Building 108/Underground Storage Tank Area Area (B108), and the Borrow Compactor Area (BCA). The presentation is limited here to discussing those compounds that represent the highest mass fraction in the plume emanating from each source. A more complete presentation is provided in Appendix C.

5.3.2.3.4 Equalization Basins

The calibration results for several of the highest concentration compounds found in the vicinity of the EQ Basins is presented in Figures 5.34. The compounds are chlorobenzene (Figure 5.34a), 2-chlorotoluene (Figure 5.34b) and 1,2-dichlorobenzene (Figure 5.34c). The presence of these compounds is consistent with the historical records pertaining to the FSD and B108 operations with which the EQ Basins were associated. The results include pumping and monitor wells that are located downstream of, and in close proximity to the basins.

Overall, the data presented in Figures 5.34 show that the model predicts both the magnitude in concentration and the change in concentration with time. Recall that the trend in time is an important model attribute because it verifies that the source model is accounting for the major processes affecting the mass loading rate. Both the data and the model are showing that the EQ Basin source has been, and is currently, leaching mass at a fairly steady rate. This behavior is expected of a source that has reached equilibrium with its environment (i.e., no more mass is being added to the source area, and what mass remains in leaching at a steady rate).

In addition, recall that the source model treats the source mass as a uniform mixture of chemicals, the quantity and composition of which is determined from source area characterization. The uniform mixture constraint is imposed for computational reasons, and it is the basis upon which to compute the concentration of each of the nine COCs in the leachate water emanating from a given source model work block. Because the natural system is not completely uniform, the approximation of uniformity will yield results where some compounds are over-predicted and some are under-predicted. For example, compare the general over-prediction of chlorobenzene (Figure 5.34a) with the general under-prediction of 1,2-dichlorobenzene (Figure 5.34c).

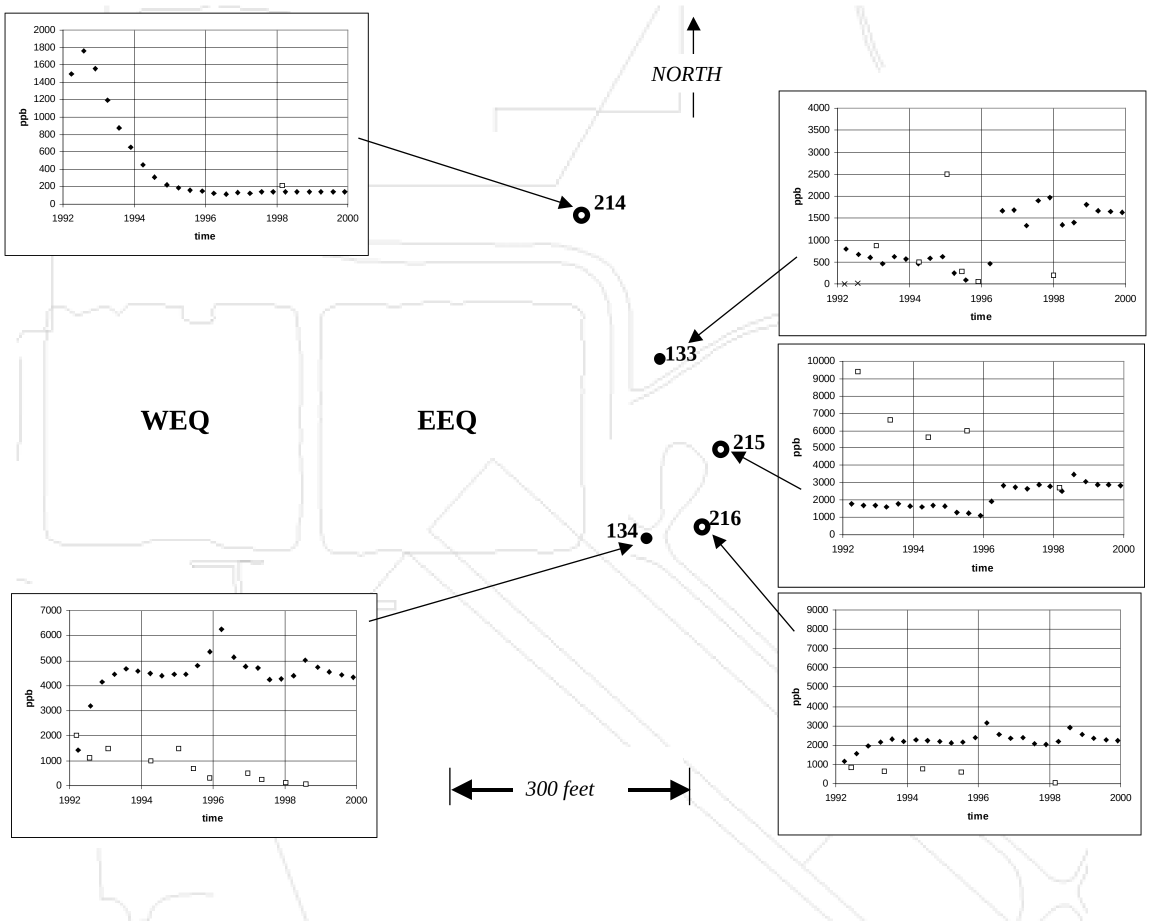

Figure 5.34a – Comparison between measured data and CTM prediction for Chlorobenzene emanating from the EQ Basins at several wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

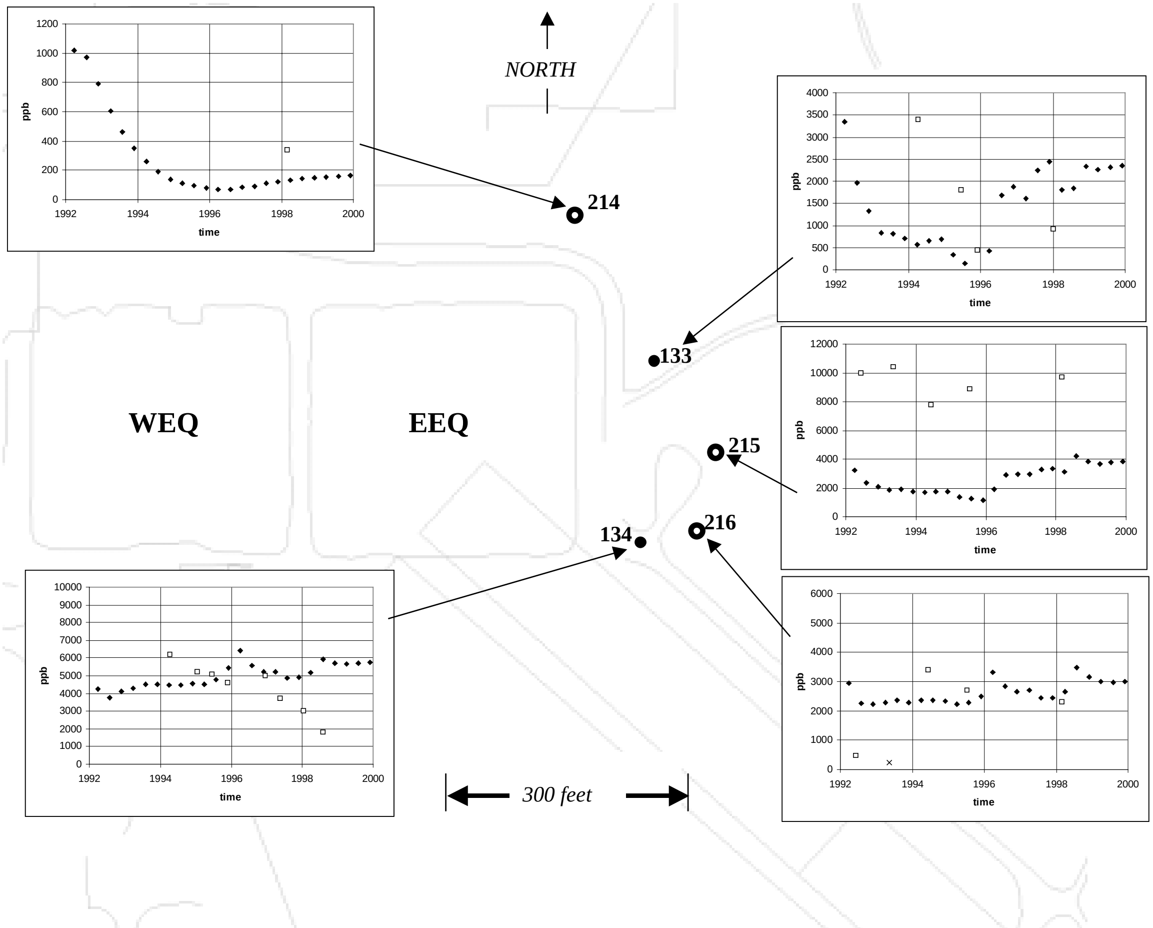

Figure 5.34b– Comparison between measured data and CTM prediction for 2-chlorotoluene emanating from the EQ Basins at several wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

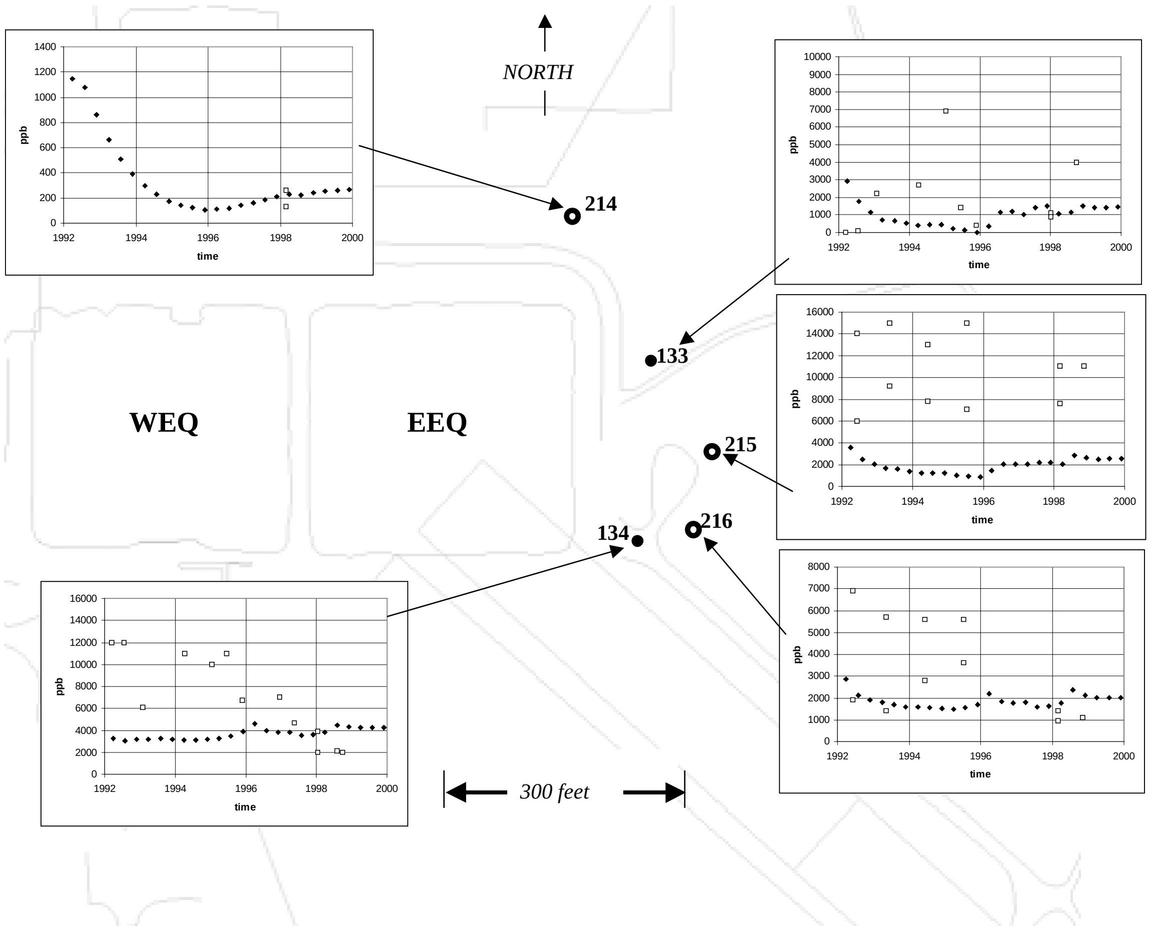

Figure 5.34c – Comparison between measured data and CTM prediction for 1,2-dichlorobenzene emanating from the EQ Basins at several wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

5.3.2.3.5 Former South Dye Area

The calibration results for several of the highest concentration compounds found in the vicinity of the Former South Dye Area (FSD) is presented in Figures 5.35. The compounds include chlorobenzene (Figure 5.35a), 2-chlorotoluene (Figure 5.35b) and 1,2-dichlorobenzene (Figure 5.35c). Note that these compounds are the same as those found in the vicinity of the former EQ basins. This is because the EQ Basins were part of the treatment system for the FSD operation wastewater.

Figures 5.35 show the calibration results for two monitor wells located downstream of, and in close proximity to the FSD. While this database is insufficient to verify the modeled time trend in concentration, the model results are consistently within a factor of two of the measured results.

Because there are no well data to support concentration trend with time, source model parameter definition was based, in addition to the data shown here, on an assessment of the leaching properties of the sub-area associated with the Bioremediation Pilot Study. Appendix E-1 provides a detailed description of the study, and Appendix C provides the source modeling analysis conducted to quantify the mass loading rate from the bio-pilot source work blocks. The area used in the study is located in the FSD area (see Figures 5.35, the box with the name ‘bio-pilot’), and the cell’s geo-hydrologic environment is similar to that found throughout the FSD area.

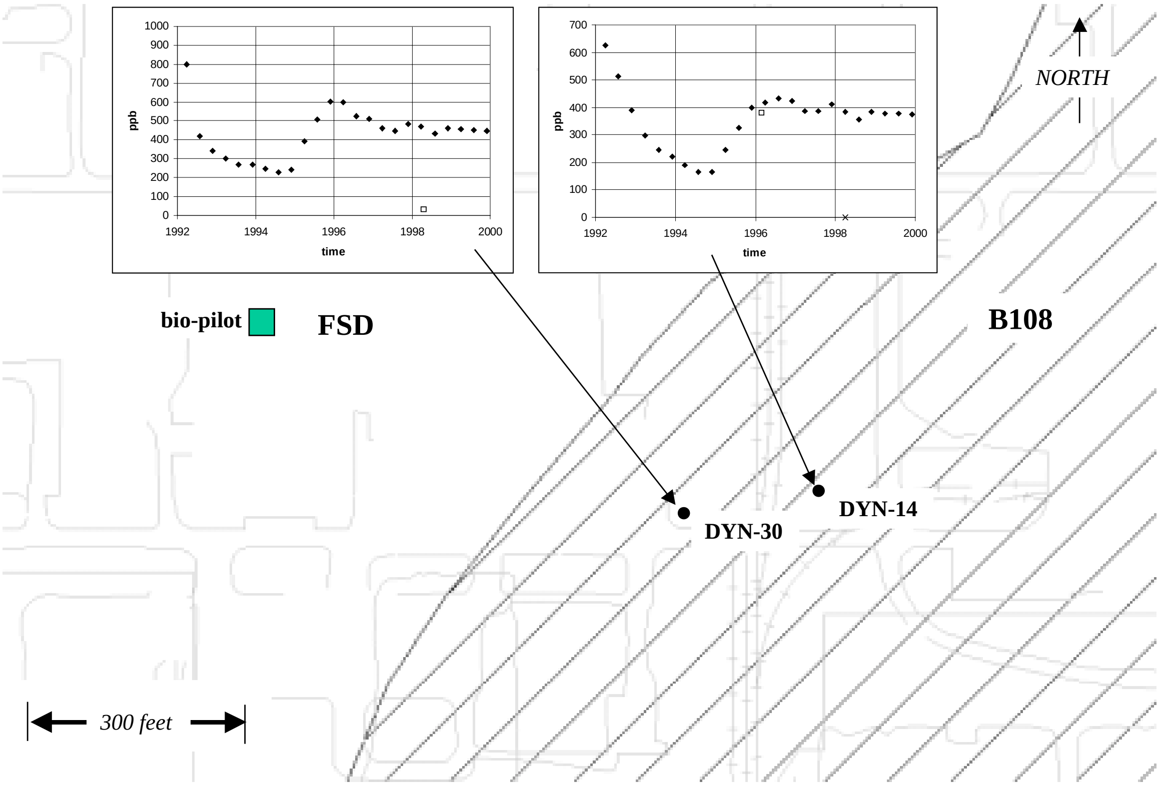

Figure 5.35a– Comparison between measured data and CTM prediction for chlorobenzene emanating from the Former South Dye Area at two wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number. The cross-hatching indicates an area where the Yellow Clay is absent.

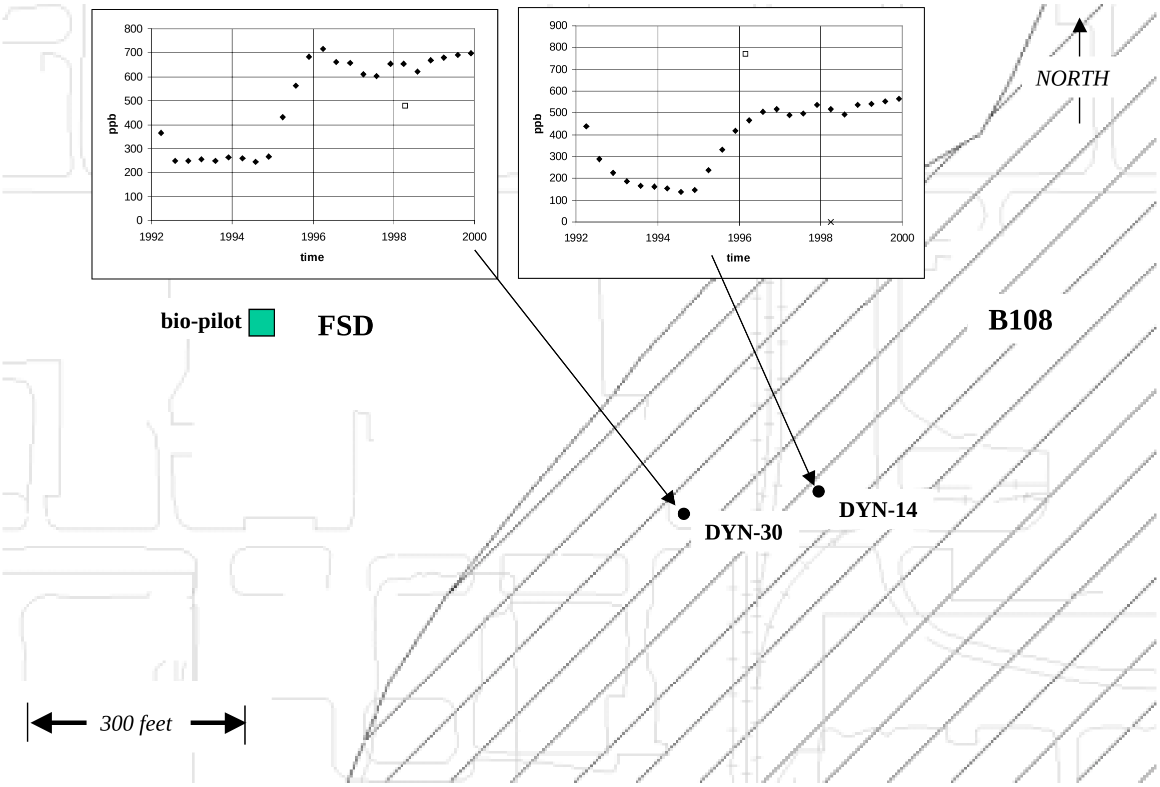

Figure 5.35b– Comparison between measured data and CTM prediction for 2-chlorotoluene emanating from the Former South Dye Area at two wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number. The cross-hatching indicates an area where the Yellow Clay is absent.

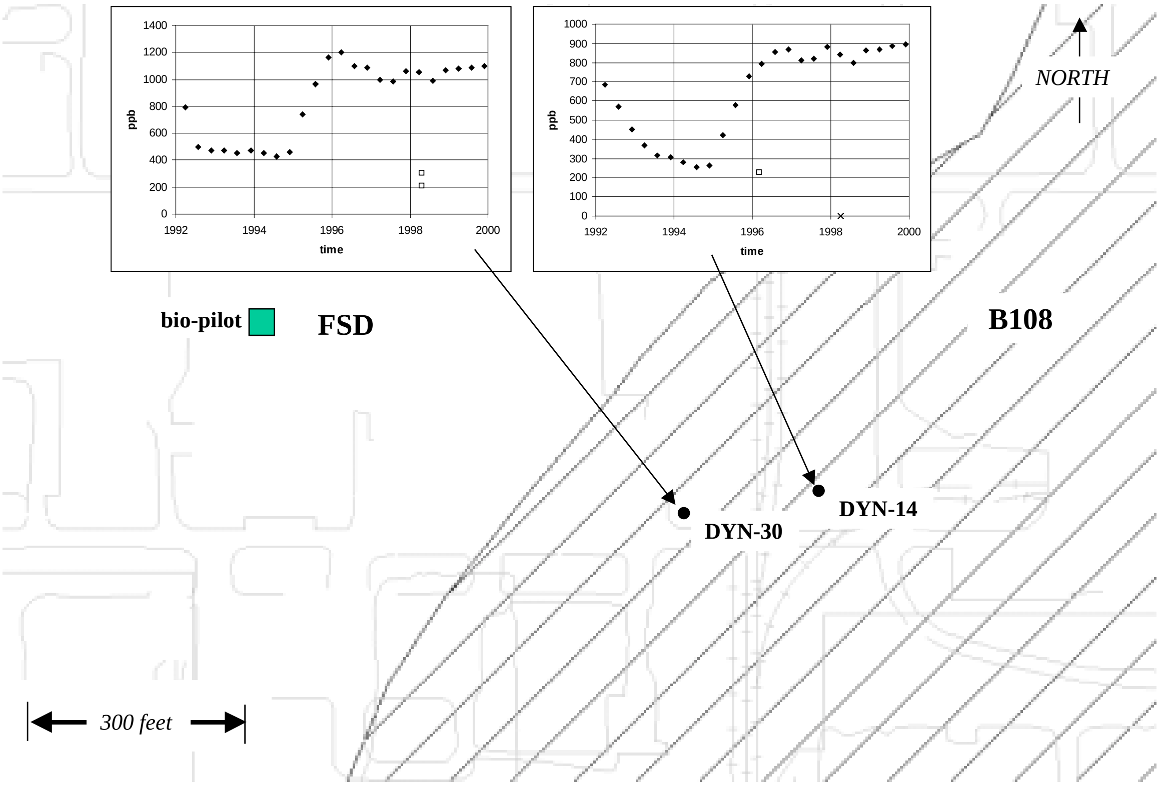

Figure 5.35c – Comparison between measured data and CTM prediction for 1,2-dichlorobenzene emanating from the Former South Dye Area at two wells located down-gradient of and in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number. The cross-hatching indicates an area where the Yellow Clay is absent.

5.3.2.3.6 Former Building 108/Underground Storage Tank Area

The calibration results for several of the highest concentration compounds found in the vicinity of the Former Building 108/Underground Storage Tank Area (B108) is presented in Figures 5.36. As with both the EQ Basins and the FSD, the compounds include chlorobenzene (Figure 5.36a), 2-chlorotoluene (Figure 5.36b) and 1,2-dichlorobenzene (Figure 5.36c).

As with the Former South Dye Area, this database is insufficient to verify the modeled time trend in concentration. For what data are available, the model predictions are consistently within the correct order of magnitude. The variability within the source area is shown by the data at wells DYN-15 and DYN-36. Although these wells are separated by only a short distance, the data show a considerable variability in concentration magnitude. The CTM provides a more uniform result which approximates an average of the data.

In this case, in addition to matching what field data are available in the vicinity of the B108 area, the source model parameters were determined based on a self-consistency with the EQ basin parameters, a similar hydro-geologic environment.

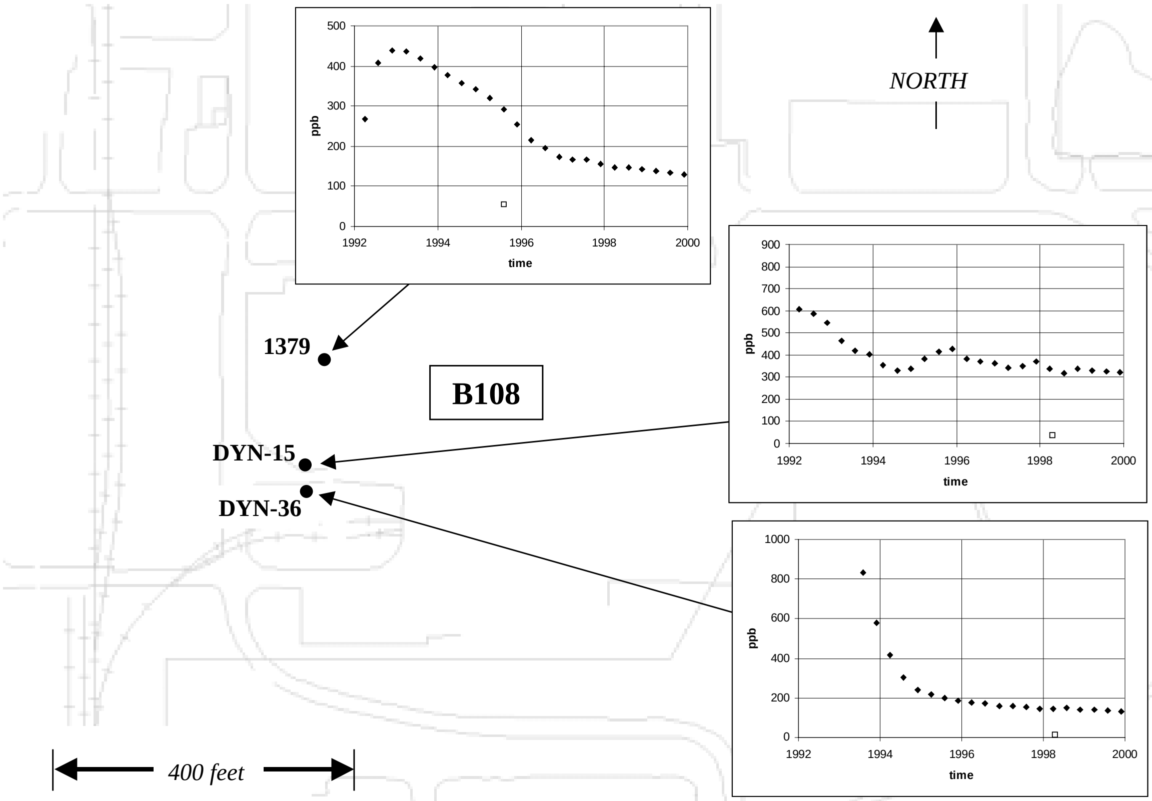

Figure 5.36a – Comparison between measured data and CTM prediction for chlorobenzene emanating from the Building 108 Area at three wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number.

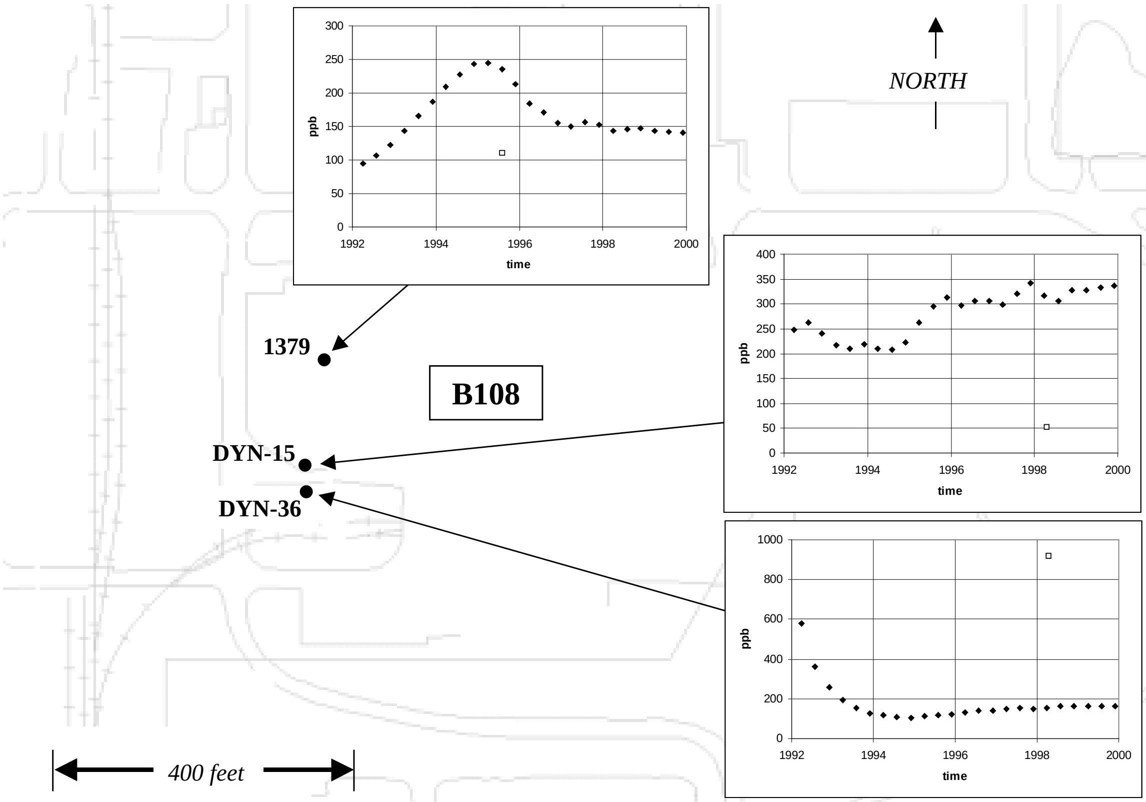

Figure 5.36b – Comparison between measured data and CTM prediction for 2-chlorotoluene emanating from the Building 108 Area at three wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number.

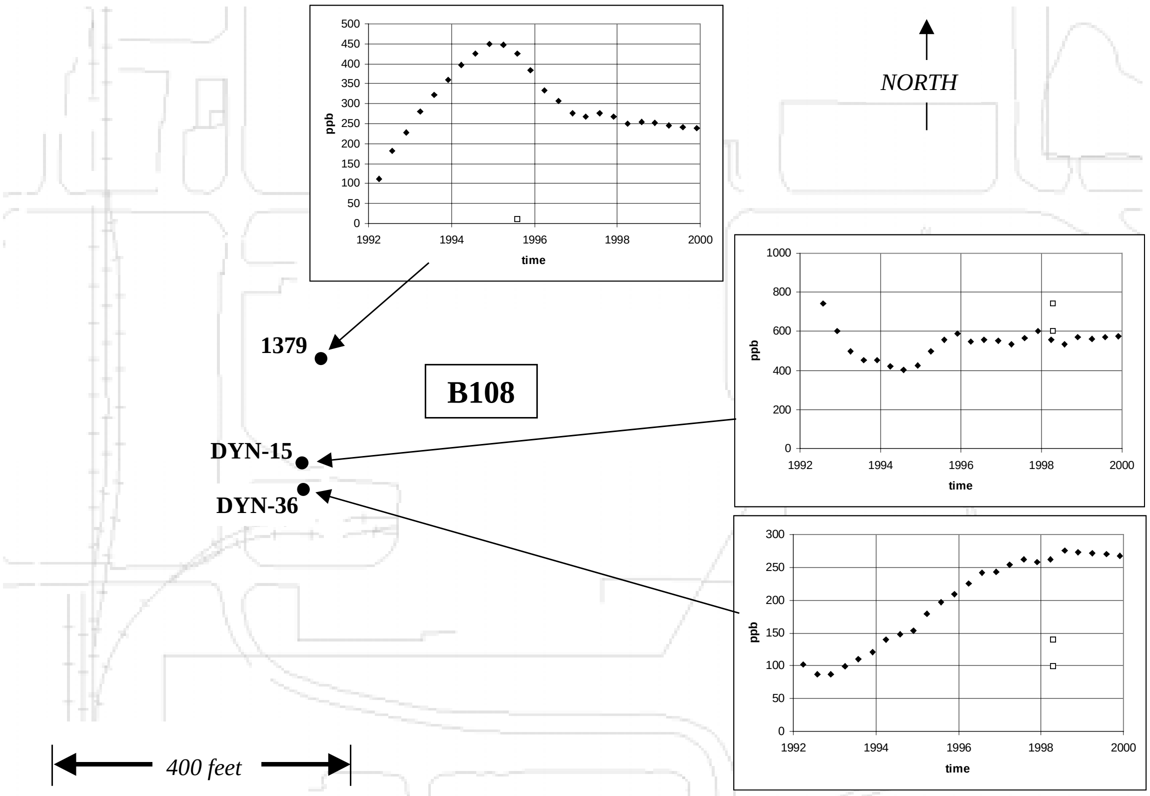

Figure 5.36c – Comparison between measured data and CTM prediction for 1,2-dichlorobenzene emanating from the Building 108 Area at three wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number.

5.3.2.3.7 Borrow Compactor Area

The calibration results for several of the highest concentration compounds found in the vicinity of the Borrow Compactor Area (BCA) is presented in Figures 5.37. Here we include pumping and monitor wells that are located in close proximity of the BCA.

The BCA is an isolated source area, and its contaminant composition is not necessarily associated with any other source area in particular. For example, the compounds that represent most of the contaminant mass emanating from this source area, and those shown in Figures 5.37, are chlorobenzene (Figure 5.37a), trichloroethene (Figure 5.37b), and naphthalene (Figure 5.37c).

With respect to the data, note that the concentrations associated with the contaminant plume emanating from this source are much lower that those associated with the other North plume sources (on the order of parts per billion). The CTM reflects these low concentrations, as well as concentration trends where available (see well 146).

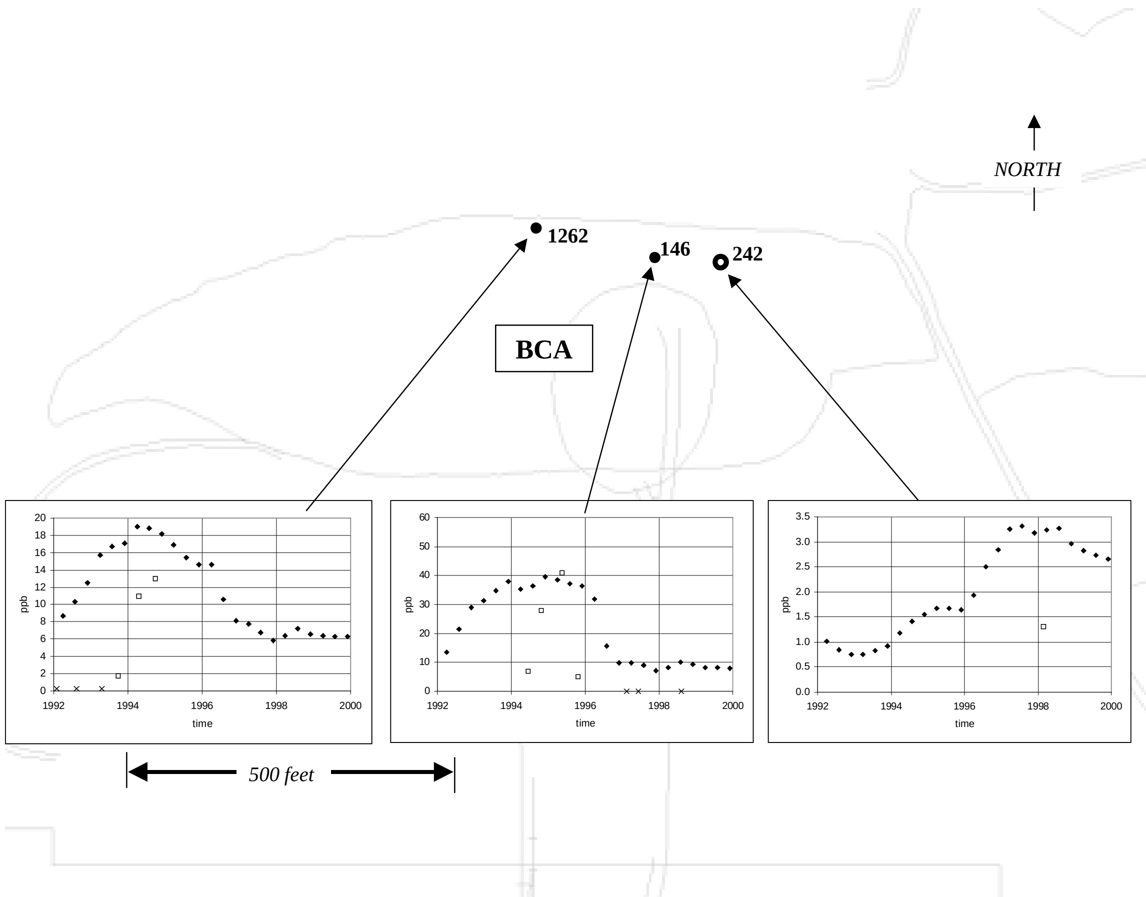

Figure 5.37a– Comparison between measured data and CTM prediction for chlorobenzene emanating from the Borrow Compactor Area at several wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

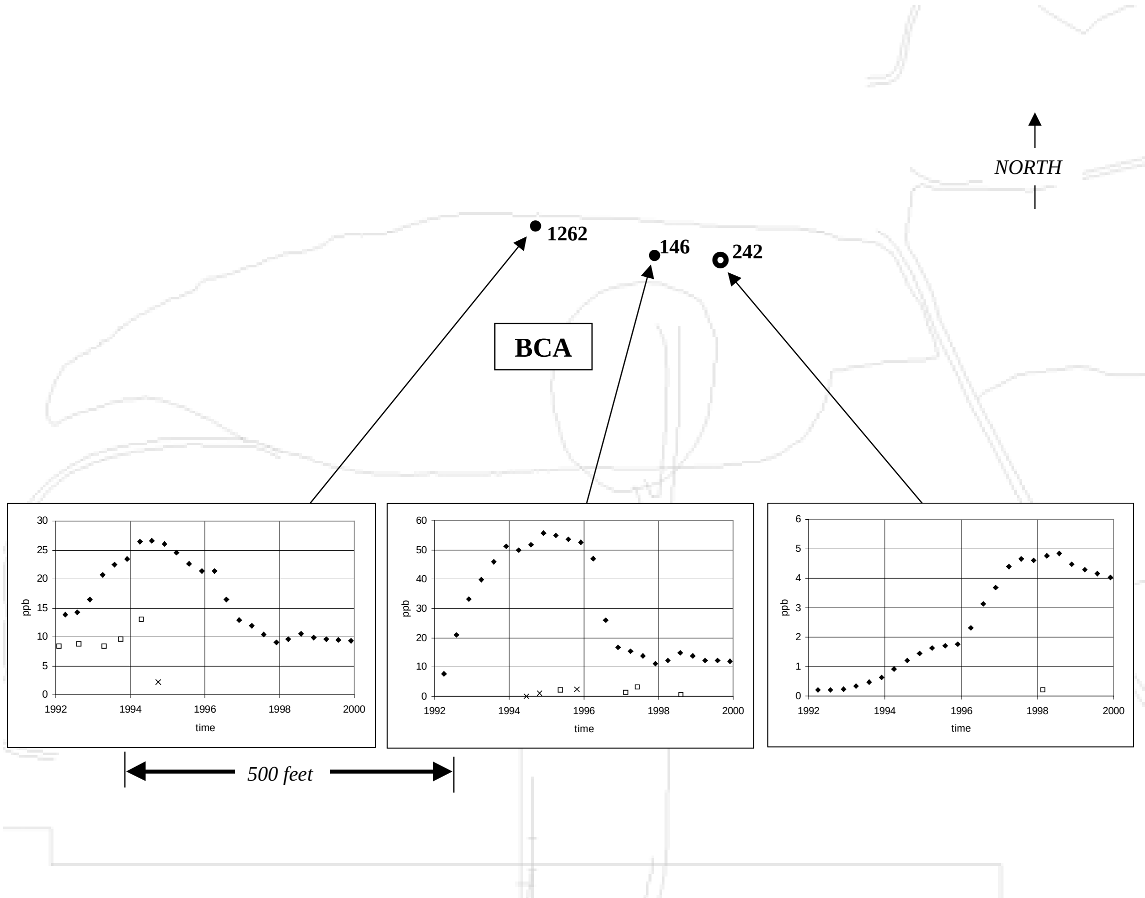

Figure 5.37b – Comparison between measured data and CTM prediction for trichloroethene emanating from the Borrow Compactor Area at several wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

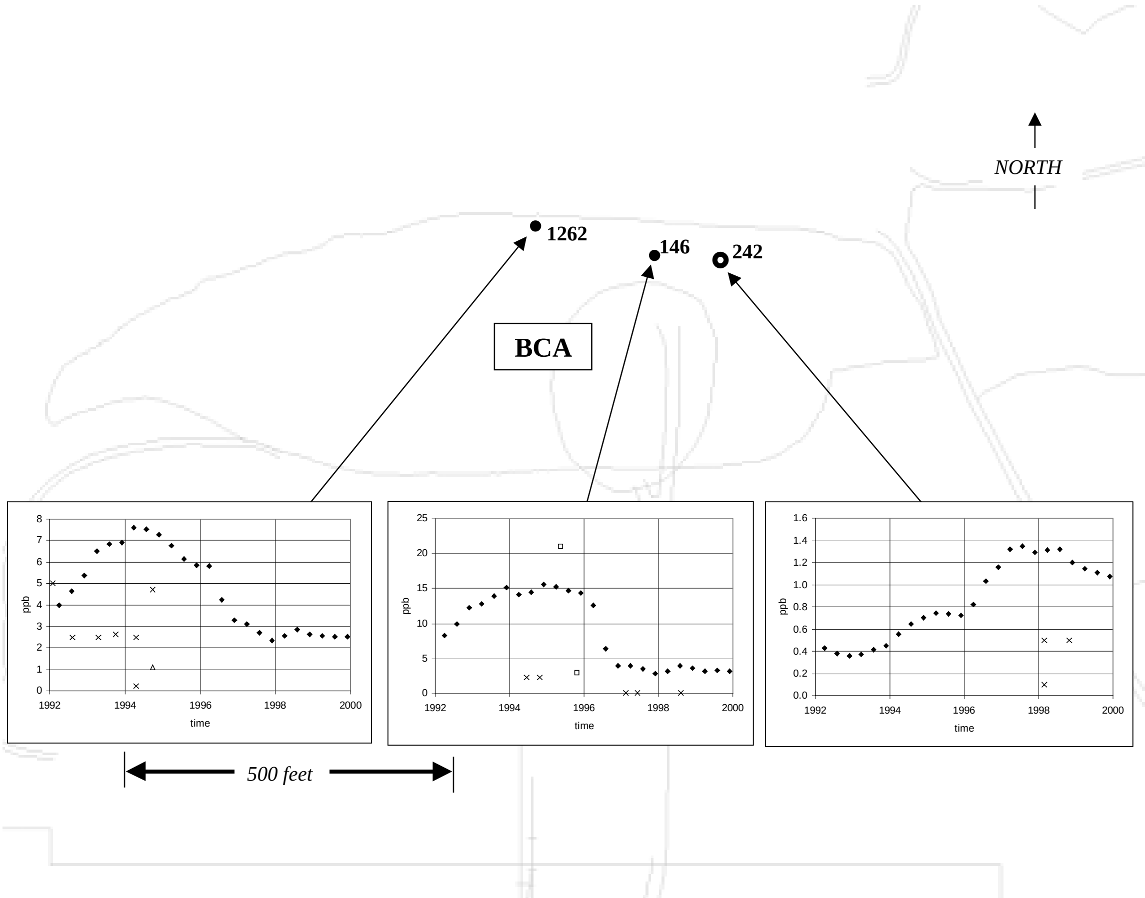

Figure 5.37c – Comparison between measured data and CTM prediction for naphthalene emanating from the Borrow Compactor Area at several wells located in close proximity to the source. The plots show the trend in concentration (units of [ppb]) versus time, where the solid diamonds represent a CTM result, the open squares represent an unqualified measured value, the open triangles represent a diluted sample estimate, and the crosses represent ½ the detection limit if the result indicated not detected. The wells are identified by number, and the pumping wells are represented by open circles while monitor wells are identified by solid circles.

5.3.2.3.8 Summary

The following bullets represent a summary of the major points contained in this section on North plume calibration:

- Four major source areas were modeled using the CTM to determine their current and future impact to groundwater contamination: the Equalization Basins (EQ Basins), the Former South Dye Area (FSD), the Former Building 108/Underground Storage Tank Area (B108), and the Borrow Compactor Area (BCA).

- Four unique pumping well configurations existed at the Site (the GERS configuration is currently operating). These configurations had a major impact on contaminant mass distribution in the northern part of the aquifer. Most notably, the production wells, operating between 1953 and 1985, caused contaminant mass from the EQ Basins to migrate in a more northerly direction than it would otherwise have under natural flow conditions.

- A significant amount of contaminant mass entered the aquifer as a dissolved phase in infiltrating plant process wastewater. When plant operations ceased, this source for contamination was eliminated from the system. Because the historical trend in mass flux rate from this source cannot be determined with any certainty, it cannot be readily modeled. As a result, the calibration exercise presented above isolated that part of the database which had a minimal impact on this former source.

- An attempt was made to fit measured data where available. Measured data include water quality measurements at pumping and monitor wells downstream of, and in close proximity to, each source area.

- Where data are limited for calibration of a particular source model work block, an effort was made to assess other work blocks with a similar geology and hydrology to obtain a self-consistency. For example, the B108 work blocks have source model parameters that are similar in magnitude as those associated with the EQ Basin work blocks.

- In the FSD source model parameters were defined based on measurements taken from the bio-pilot cell. The appropriateness of the values were then assessed based on available monitor well data located in close proximity of the source.

- The BCA is an isolated source, leaching low levels of contamination.

5.4 CTM Applications

Recall from Section 5.2, that the objective for developing and calibrating the CTM is two fold:

1. To help characterize the nature and extent of groundwater contamination at the Site.
2. To aid in the *Feasibility Study* (FS) process by providing a cause-and-effect relationship between the sources for groundwater contamination and groundwater quality downstream of those sources.

With regard to item (2) above, the CTM is derived to provide a functional relationship between the physical attributes of a work block (i.e., residual contaminant mass, hydrology and geology) and the rate at which dissolved contaminants leach from the work block. With this relationship in place, the CTM can be used to assess remediation alternatives. Specifically, if a particular remediation scenario can be associated with a change in one or more source model parameters, then the CTM can be used to assess the impact that that scenario will have on aquifer restoration. For example, excavation, ex-situ treatment and replacement of work block soil can be associated with a reduction in work block contaminant mass which results in a reduction in the dissolved mass loading rate (see Table 5.6). In addition, the installation of hydraulic controls, such as a surface cap or a barrier wall, will reduce the groundwater flux rate through the work block, and thus reduce the dissolved mass loading rate to the aquifer. A reduction in the dissolved mass loading rate results in a reduction in the concentration of contaminants in the aquifer (see Table 5.5).

During FS activities, the calibrated CTM is used to quantify the relationship between source area remediation and the following remediation parameters:

- *Baseline Time of Compliance* - under the hypothetical, ideal, scenario that all current sources for contaminant mass are removed from the system, assess the time it takes for the aquifer to be restored.
- *Preliminary Remediation Goals* – quantify the necessary level of source area remediation so the groundwater quality standards are met throughout the affected aquifer at a particular time of compliance.

The topic of developing the Preliminary Remediation Goals (PRGs) for the Site is presented in Section 6. The remainder of this Section is dedicated to discussing the concept of an appropriate time of compliance over which to apply the PRGs.

5.4.1 BASELINE TIME OF COMPLIANCE

The baseline time of compliance (TOC) is used to assess the minimum time required to achieve groundwater performance standards throughout the plume for each contaminant of concern. As such, it provides an end-point for the full impact of source area remediation.

This analysis is based on the hypothetical scenario that there is no additional mass loading from source areas to the aquifer. With this constraint, we are interested in answering the question: how long will it take for the current contaminant plume to attenuate under GERS pumping conditions, so that groundwater performance standards are met throughout the impacted aquifer? This time-line is called the *baseline time of compliance* (TOC).

To illustrate the concept, let us present the analysis for a particularly recalcitrant compound, 1,2,4-trichlorobenzene (1,2,4-TCB). A more detailed analysis is provided in Appendix C, where it is shown that 1,2,4-TCB is one of the last compounds to attenuate to below the groundwater performance standard defined for the site.

The first step in the analysis is to define a representative groundwater flow field, which is based on the following flow stress inputs:

1. The current GERS system operating at a constant rate equivalent to each well pumping at its average recorded rate from 3/96 through 2/98.
2. The average Toms River stage recorded at the USGS gage station from 1953 through 1998 (12.4 feet above MSL).
3. The average infiltration rate as derived from Toms River base flow records from 1953 through 1998 (20.17 inches per year).

The next step is to define an appropriate initial condition for the contamination distribution within the aquifer. In other words, here we define the current plume conditions. For this analysis, the initial conditions are based on the calibrated CTM solution for the site-wide contamination problem. Figures 5.38a and 5.38b show the current 1,2,4-TCB plume, as approximated by the CTM, in the bottom of the Primary Cohansey and in the Lower Cohansey, respectively. Note that, it is in the Primary Cohansey that the current plume has its largest areal extent.

The final set-up phase of the analysis involves defining the appropriate contaminant transport parameters that affect future mass distributions within the aquifer. The most important parameters include the following:

1. Hydrodynamic dispersion coefficients – defines how the plume spreads out over time. These values were defined during model calibration.
2. Chemical-specific partition coefficient (K_d) – defines the relative speed that each COC moves within the aquifer. The values employed herein are based on both site-specific measurements and CTM calibration results.
3. Chemical-specific first-order biodegradation coefficient (λ) – defines whether a particular COC is susceptible to biological degradation, and if so the rate at which mass is lost from the system. This phenomenon effectively reduces the concentration of a compound over time. The magnitude of the rate is often given in terms of a compound's half-life (the concentration is reduced by one half over

regular time intervals). For example, the half-life for 1,2,4-TCB used herein is 38 years (i.e., 20ppb will decline to 10ppb in 38 years due to biological processes). This rate is relatively low, and it is intended to represent a site-wide average over long periods of time. That is locally, under ideal conditions, the rate can be much higher (see results from the Bioremediation Pilot Study, Appendix E-1).

Given the required model input parameters, we are now poised to simulate how the 1,2,4-TCB plume shown in Figures 5.38 evolves as time progresses into the future.

5.4.1.1 Results and Discussion

The results are intended to quantify and illustrate two important attributes regarding the site:

1. The baseline TOC.
2. Those zones in the aquifer where restoration takes the longest.

The second issue is related to the concept that plume restoration time can be minimized by altering the groundwater flow patterns in and around those aquifer zones where restoration takes the longest.

Figures 5.39a through 5.39e illustrate 1,2,4-TCB plume evolution as a function of time from initial (current) conditions (i.e., time 5, 10, 20, 30, 40 years, respectively). Each time frame shows that portion of the aquifer where the plume has its largest areal extent. Note that the plume reduces in size over time. Also, note that the Primary Cohansey cleans up faster than the Lower Cohansey. As shown, a small amount of contamination remains in the Lower Cohansey at 40 years into the future. Thus, from this analysis the 1,2,4-TCB plume “attenuates” in approximately 40 years.

In addition to illustrating the TOC, the plots also illustrate the concept that certain parts of the aquifer clean up faster than do others. Specifically, the isolated Lower Cohansey plume shown in Figures 5.39c through 5.39e are associated with low flow aquifer conditions. These conditions may be enhanced by GERS pumping, for example by causing stagnation zones in the aquifer.

5.4.1.2 Conclusions

In this Section, we provided an example of how the contaminant plume cleans up (attenuates) over time under the hypothetical (ideal) scenario that all the source areas are removed from the system. The analysis shows that with no additional mass loading from sources and with the continued operation of the GERS, the 1,2,4-TCB plume will fully attenuate in approximately 40 years. As discussed in more detail in Appendix C, when addressing all nine contaminants of concern, the attenuation time ranges from approximately 20 years to 40 years.

Considering the concept that the GERS can be "optimized" to both capture the existing plume and to remove contaminant mass from the system, one can be reasonably confident that the rate of plume size reduction can be enhanced over that shown in Figures 5.39. GERS optimization involves reassessing both the location of pumping wells and the rate at which the wells pump as a function of plume geometry.

Considering this information, a baseline time of compliance of 30 years has been chosen for this Site.

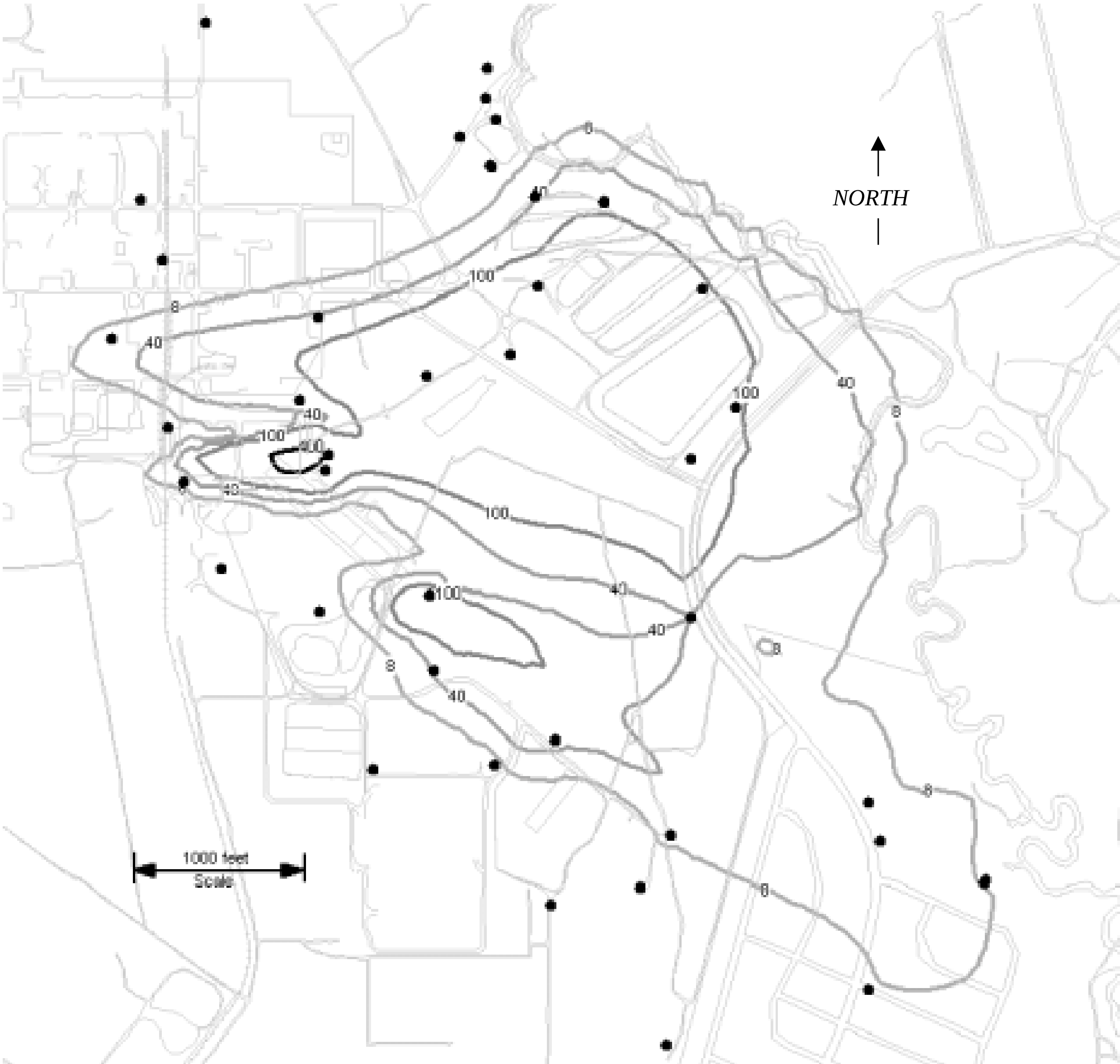

Figure 5.38a: The initial condition for the 1,2,4-TCB plume in the bottom of the Primary Cohansey (the part of the aquifer where the plume area is largest). The concentration contours shown are 400, 100, 40, and 8 [ppb] (the groundwater restoration standard). The black dots represent the location of a GERS well.

Figure 5.38b: The initial condition for the 1,2,4-TCB plume in the Lower Cohansey. The concentration contours shown are 100, 40, and 8 [ppb] (the groundwater restoration standard). The black dots represent the location of a GERS well.

Figure 5.39a: The 1,2,4-TCB plume after 5 years in the bottom of the Primary Cohansey (the part of the aquifer where the plume area is largest). The GERS wells (black dots) are pumping at their average rates, and the sources for contaminant mass have been turned off. The concentration contours shown are 100, 40, and 8 [ppb] (the groundwater restoration standard).

Figure 5.39b: The 1,2,4-TCB plume after 10 years in the bottom of the Primary Cohansey (the part of the aquifer where the plume area is largest). The GERS wells (black dots) are pumping at their average rates, and the sources for contaminant mass have been turned off. The concentration contours shown are 40 and 8 [ppb] (the groundwater restoration standard).

Figure 5.39c: The 1,2,4-TCB plume after 20 years in the Lower Cohansey (the part of the aquifer where the plume area is largest). The GERS wells (black dots) are pumping at their average rates, and the sources for contaminant mass have been turned off. The concentration contours shown are 20 and 8 [ppb] (the groundwater restoration standard).

Figure 5.39d: The 1,2,4-TCB plume after 30 years in the Lower Cohansey (the part of the aquifer where the plume area is largest). The GERS wells (black dots) are pumping at their average rates, and the sources for contaminant mass have been turned off. The concentration contours shown are 12 and 8 [ppb] (the groundwater restoration standard).

Figure 5.39e: The 1,2,4-TCB plume after 40 years in the Lower Cohansey (the part of the aquifer where the plume area is largest). The GERS wells (black dots) are pumping at their average rates, and the sources for contaminant mass have been turned off. The concentration contour shown is 8 [ppb] (the groundwater restoration standard).